MODERN AMERICAN MACHINE TOOLS

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THIS BOOK

IS DEDICATED TO

ALBION P. BENJAMIN

WHO FIRST SHOWED ME

THE RIGHT AND WRONG OF

MACHINE CONSTRUCTION

PREFACE

Such books on machine tools as have been published hitherto have treated the subject mainly from the standpoint of the apprentice or the journeyman, and have described the details of adjustment and operation rather than the design and construction of the machines themselves. It is the object of this treatise to show to the buyer and user the prominent characteristics of modern machine tools as now manufactured in the United States, the various points in which they differ, and some recent data as to their capacity and performance. It is hoped that this book may also be of interest and profit to the manufacturer of metal-working machinery as showing the general trend of machine design and the more recent developments.

To the buyer in Great Britain or on the Continent this work should be a help, as it brings together in one volume facts from a variety of sources, and furnishes information which might otherwise need to be sought at much expenditure of time and trouble.

In deciding upon the types of machines to be considered, it has been thought best to exclude special machinery which is used for a limited line of manufacture, and to include only those machines which would find use in a general machine shop.

The list then includes planing, turning, boring, and drilling machinery, milling and grinding machines, and finally

machinery for shearing and punching metal and for cutting screw threads.

Chapter XII. aims to give a review of the subject of machine-tool design, to show recent improvements, and the direction in which to look for further progress.

While the present work is in no sense an advertising medium, an endeavour has been made to illustrate as large a variety of machines and of makes as the limits of space would allow.

The writer wishes to acknowledge his indebtedness to the manufacturers whose kindness in the matter of furnishing photographs has made possible the illustration of the book, and to express his regret that the natural limitations of space have made it impossible to illustrate all the machines mentioned.

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CHAPTER I

PLANING MACHINES

1. Classification.

Machines for producing plane or flat surfaces may be classified under the head of planing machines proper, or, as they are usually called, 'planers,' shaping machines or shapers, slotting machines or vertical shapers, milling or slabbing machines, and the so-called rotary planers.

Briefly described, the planer has a platen or table which carries the work against the cutting tool and back, the tool having only the transverse motion necessary for the feed.

The shaper, on the other hand, has a cutting tool which moves back and forth over the work, the latter in turn having the transverse motion of feeding.

The slotting machine is in the same general class as the shaper, but the tool slide has a vertical instead of a horizontal motion.

The milling machine with its rotary cutters belongs in a class by itself and is almost universal in its application, but in the form known as a slabbing machine develops flat surfaces only and is a formidable rival of the planer.

The so-called rotary planer, while closely allied to the milling machine, is usually distinguished by the use of a revolving head of large diameter carrying on its flat face removable cutters or tools. Its peculiar field is the facing of ends on columns or frames.

2. Planing Machines.

The principal elements of a planing machine are: (*a*) the bed or frame; (*b*) the table carrying the work; (*c*) the vertical housings connected by the top brace; (*d*) the cross-rail, carrying one or more heads and adjustable vertically on the housings; (*e*) the tool heads, similar to the compound rest of a lathe, attached either to the cross-rail or to the faces of the housings, and capable of motion vertically or horizontally; (*f*) the gearing for reciprocating the table; (*g*) the shipping or reversing gear; (*h*) the feed mechanism for operating the tool heads.

3. Planer Beds.

The bed of a planing machine varies with the type and size of machine. In general it consists of a hollow, rectangular casting with or without legs, having ways at the top for the guidance of the table and provided with bosses and projections for the attachment of the shafts and gearing. In small planers, ranging from 17 inches to 30 inches capacity, it is necessary to support the bed on legs in order to secure the necessary height of table for the convenience of the workman. Fig. 1 shows a good example of modern design for a $17'' \times 17'' \times 4'$ machine. There is an entire absence of ornament and filigree work, only plane surfaces being used; the bed overhangs the legs so as to divide up the bending moment, and to make it easier for the workman in getting around the end of the machine. The outer ends of the bed are cut away so as to give a shape of approximately uniform strength. The length of the bed should be such as to support the table throughout the full stroke, and such that, when the table is run entirely out of gear, it cannot tip up.

Some American makers quote 20 inches length of bed for every foot of table length. Cabinets may be substituted for legs in machines of larger capacity and give greater stability

without being in the way of the operator. In general this is a neat design, but it is not considered good practice to have the ways overhang the bed at the ends.

Some makers use a third leg or support under the middle of

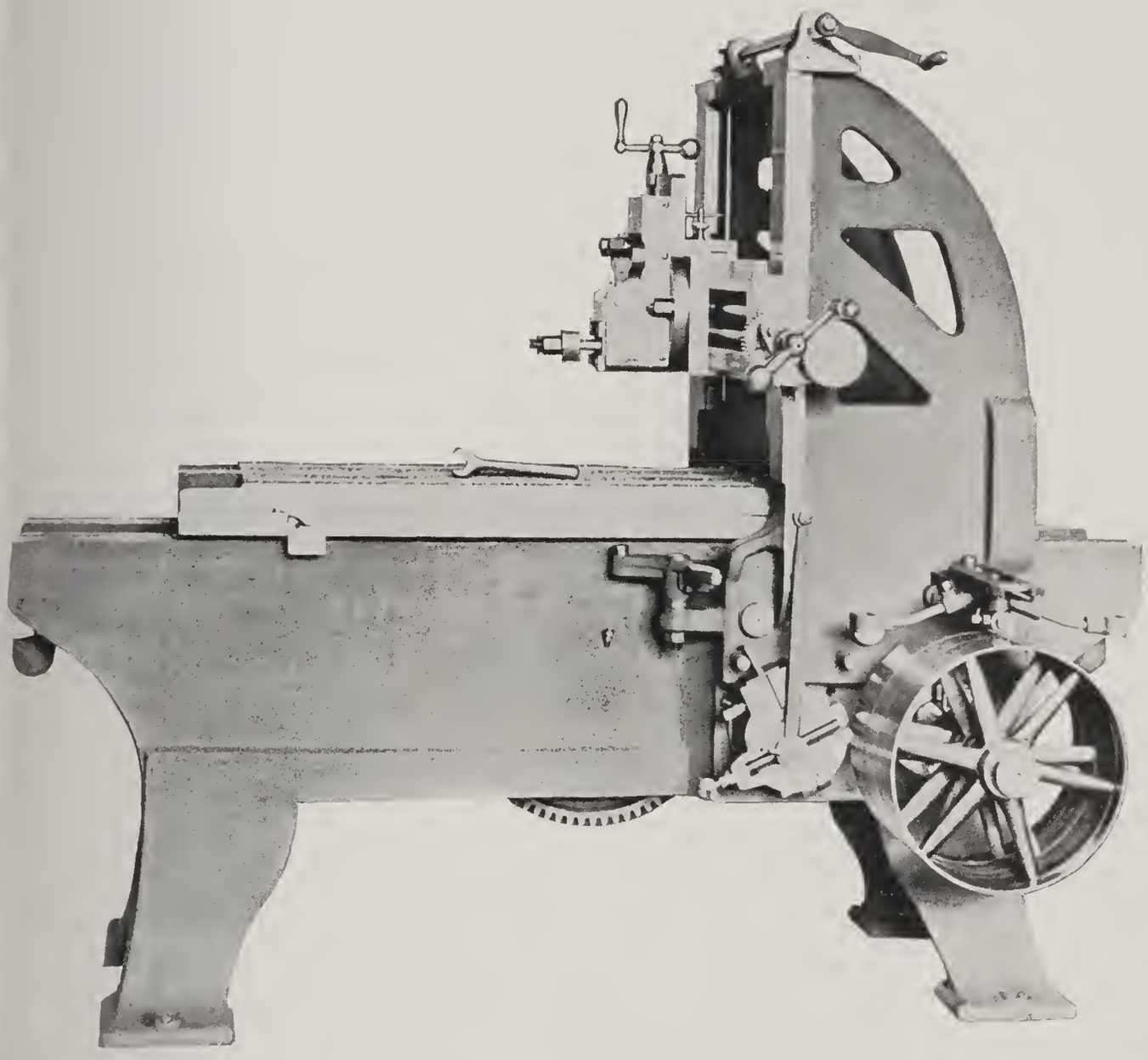

FIG. 1.

17″ × 17″ × 4′ PLANING MACHINE.

The Whitcomb Manufacturing Co., Worcester, Mass.

the length of bed, but this arrangement must be condemned. In planing machines so small as to require the use of legs the bed itself should be strong and stiff enough to carry all the load. A middle leg rarely takes its fair share of the weight, and, as one designer puts it, 'Its only use seems to be to hold the floor down.'

As the size of the machine increases, the bed becomes deeper and the legs shorter, but the same general outline is preserved.

In the larger sizes of planers, from 48 inches upward, the legs disappear altogether and the bed becomes a plain box of cast iron resting on a stone or concrete foundation. Not alone

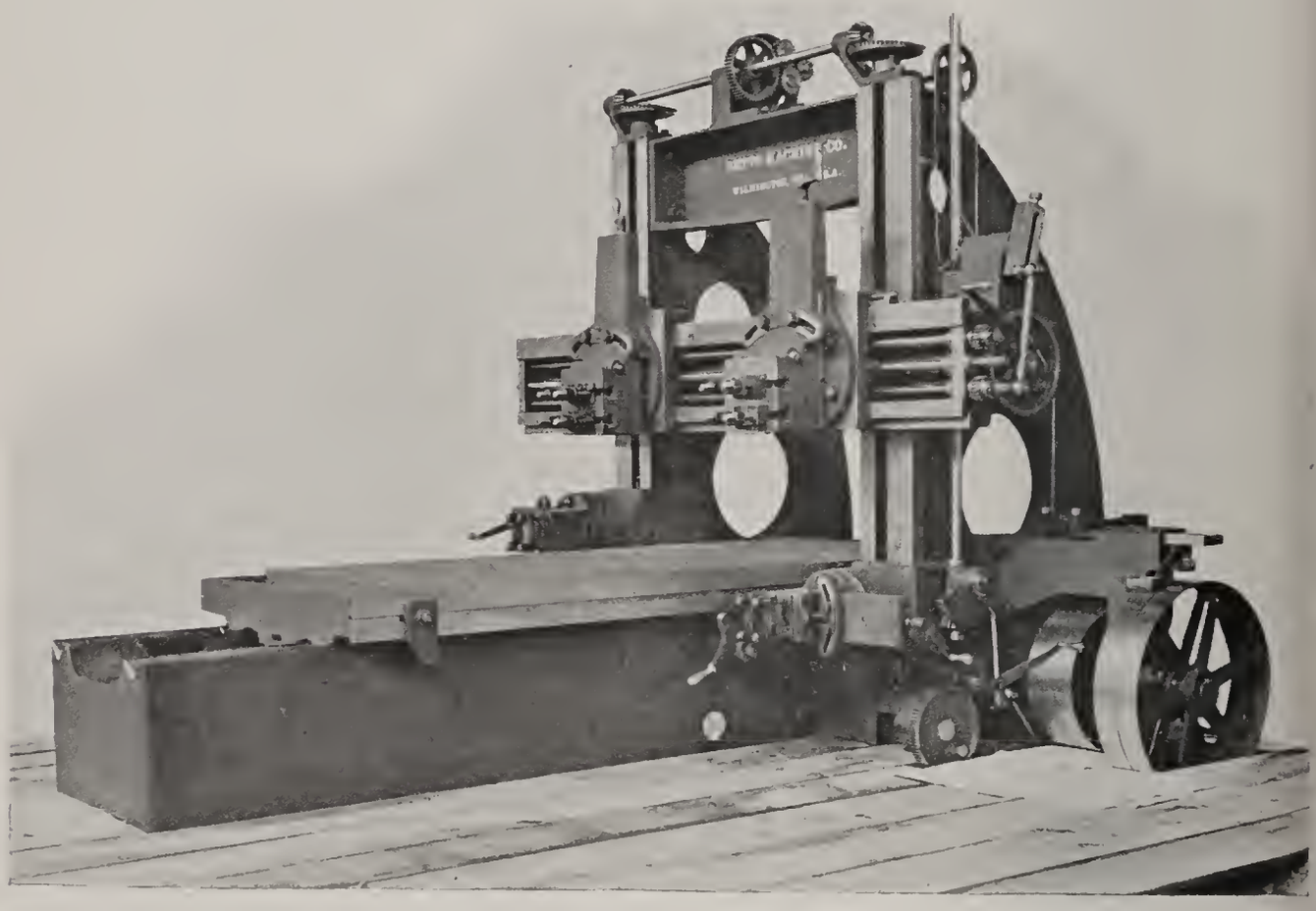

FIG. 2.

48-INCH PLANING MACHINE.

The Betts Machine Co., Wilmington, Del.

strength and rigidity are needed in this size of machine, but the bed must possess inertia and be anchored like an engine frame to withstand the shock of reversal. Fig. 2 illustrates this form of bed as used with a 48-inch planer. All of the beds illustrated are stiffened laterally by a system of interior cross-girts.

The ways for guiding the table are usually of the V form in

American practice, as this shape is readily lubricated and is self-adjusting for wear. Planers for heavy service, however, are sometimes equipped with flat ways, and in this case the table has gibbed slides to hold it in place.

The lubrication of the V's of planing machines, especially in the larger sizes, is effected by conical brass rolls (Fig. 3) dipping into oil-pockets and carrying the oil up to the ways as they revolve with the friction of the table.

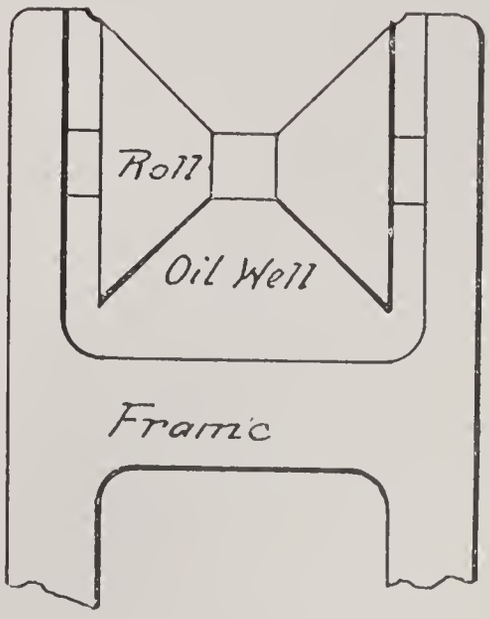

Fig. 3.
Method of Oiling Planer Ways.

Similar rolls of a cylindrical form are used with the flat ways. For extremely heavy pressures the flat way is undoubtedly the best as it is free from wedge action, but for ordinary service the V is easier to fit and to keep in repair.

4. The Table.

The principal duties of a planer table are to move smoothly and accurately upon the bed, and to keep its top surface at all times true and straight. It should be made of a moderately hard, close-grained iron, be of sufficient depth, and be thoroughly braced by longitudinal and transverse ribs underneath. There are two principal methods of driving, by spur gearing and by spiral gearing. These will be discussed in another place, and it is only necessary here to call attention to the necessity of smooth action and of sufficient strength in the gearing. The best American machines now have steel racks and pinions for driving the table, with teeth accurately cut by machinery.

The width of rack for machines from 24 to 48 inches in

capacity is from 4 to 6 inches. The angle of the V's varies somewhat in different sizes and types of planers, but is usually 90 degrees. In general this angle will be less for small machines, and greater for planers which are intended for heavy work. Instead of flat ways a very obtuse V with side edges is sometimes used as shown in Fig. 4. The T slots in the top of the table should be planed so that bolts may be easily slid from one position to another. It is extremely convenient in clamping long work to have one slot extend completely through the table. The holes for pins should all be reamed to a standard size, as nothing is more annoying than to have pins too loose or too tight in fastening work. All tables should have a depression at each end to catch oil and chips. It is, however, convenient to have pin-holes at the extreme outer end.

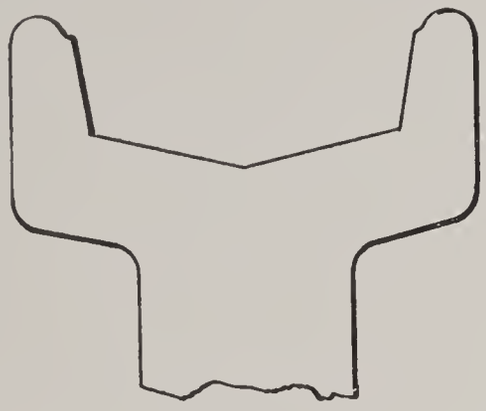

Fig. 4.

Broad V for Heavy Planer.

5. The Housings.

The upright standards to support the cross-rail, or the housings as they are usually called, are a very important part of the design. They take the whole thrust of the cutting tools and the shock of the beginning of the cut; they must be strong enough to withstand this thrust when the cross-rail is raised to its highest position, and must be stiff enough transversely to sustain the pressure of side cuts. It is hard to say just how strong and stiff they must be, but the stronger and the stiffer the better. The union of a deep bed with deep housings has been the principal cause of the increase in capacity of planing machines.

Formerly a planer was limited by its own slenderness

and fragility ; now the limit is usually the endurance of the cutting tool.

The housing of a planing machine when the cross-rail is at the top is in the condition of a bracket fixed at one end and loaded at the other. If of constant breadth from top to bottom, its profile should be a parabola with axis vertical and vertex at the load-point, to secure the maximum strength for a given weight. This form is approximated to in most American machines, as may be seen by reference to the illustrations. To secure lightness without much sacrifice of strength two or more circular holes are cut along the line of the neutral axis. These holes must be kept well away from the front vertical face, as this side is exposed to tension.

As the casting is usually of box form and cored, these apertures are available for core prints. Some makers prefer to cut apertures in such a way as to give the appearance of straight bracing as shown in Fig. 1. If properly calculated, this form may be made to give good results. Others prefer to use the straight line altogether as shown in Fig. 5. It should be said, however, that this latter machine is intended especially for heavy work near the table, and that with the cross-rail in its highest position there would be more deflection than if the parabolic housing were used.

The housings are usually secured to projecting cheeks on each side of the bed by bolts and by planed lugs and grooves. In large planers the housing should extend to the bottom of the bed and have a wide bearing surface in order to give a good leverage against the thrust of the cutting tool. Fig. 2 shows this clearly.

Those machines are to be preferred in which the housings are kept reasonably near together. The attempt to make a 42-inch out of a 36-inch planer by simply setting the housings wider apart should be discouraged.

The so-called ‘ widened planer ’ has a place of its own like the gap lathe, and does not come under the above criticism.

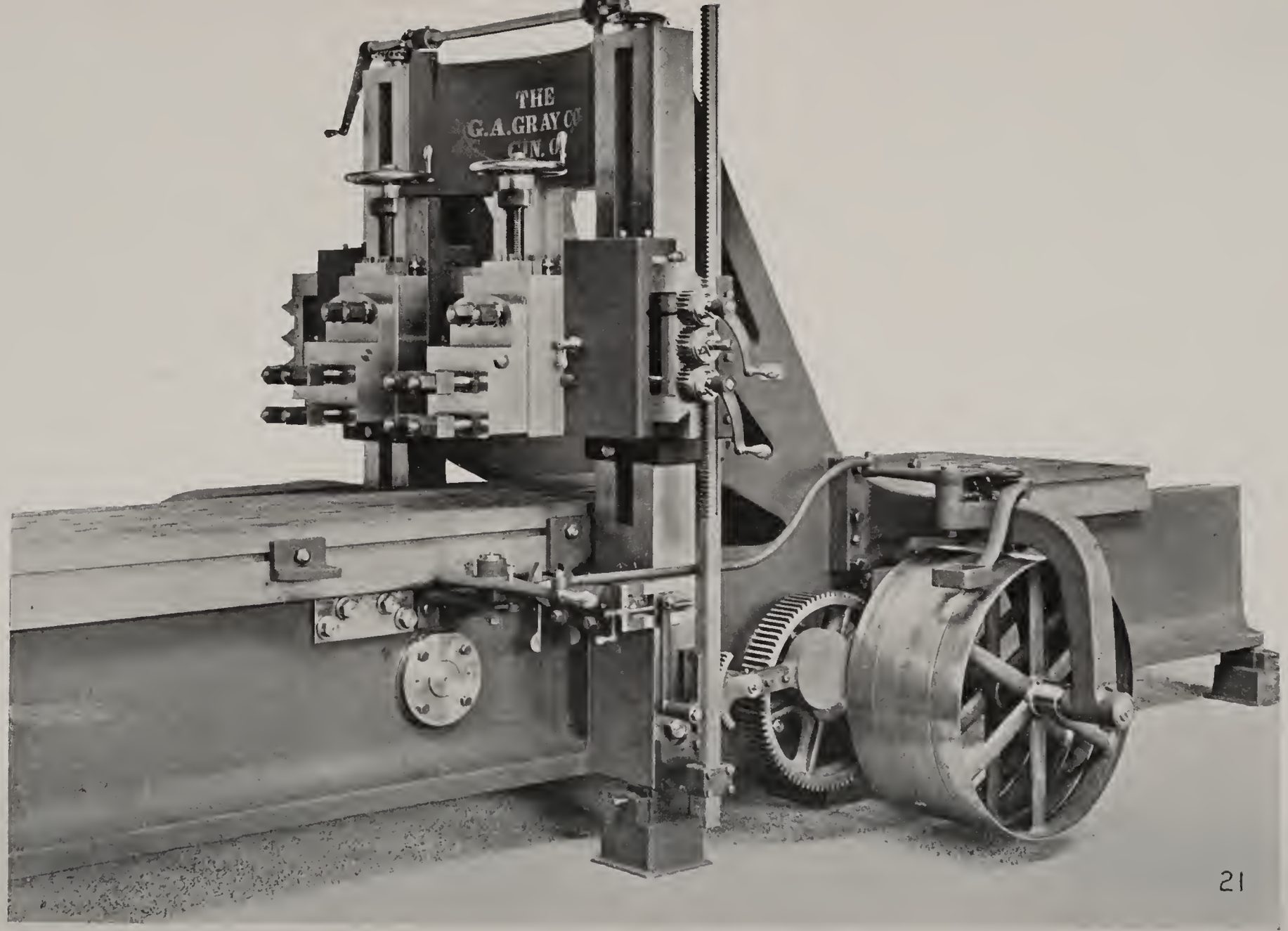

FIG. 5.

36-INCH FROG AND SWITCH PLANER.

Fig. 6 shows a planer of this description, especially adapted to handling work which is unusually wide in proportion to its

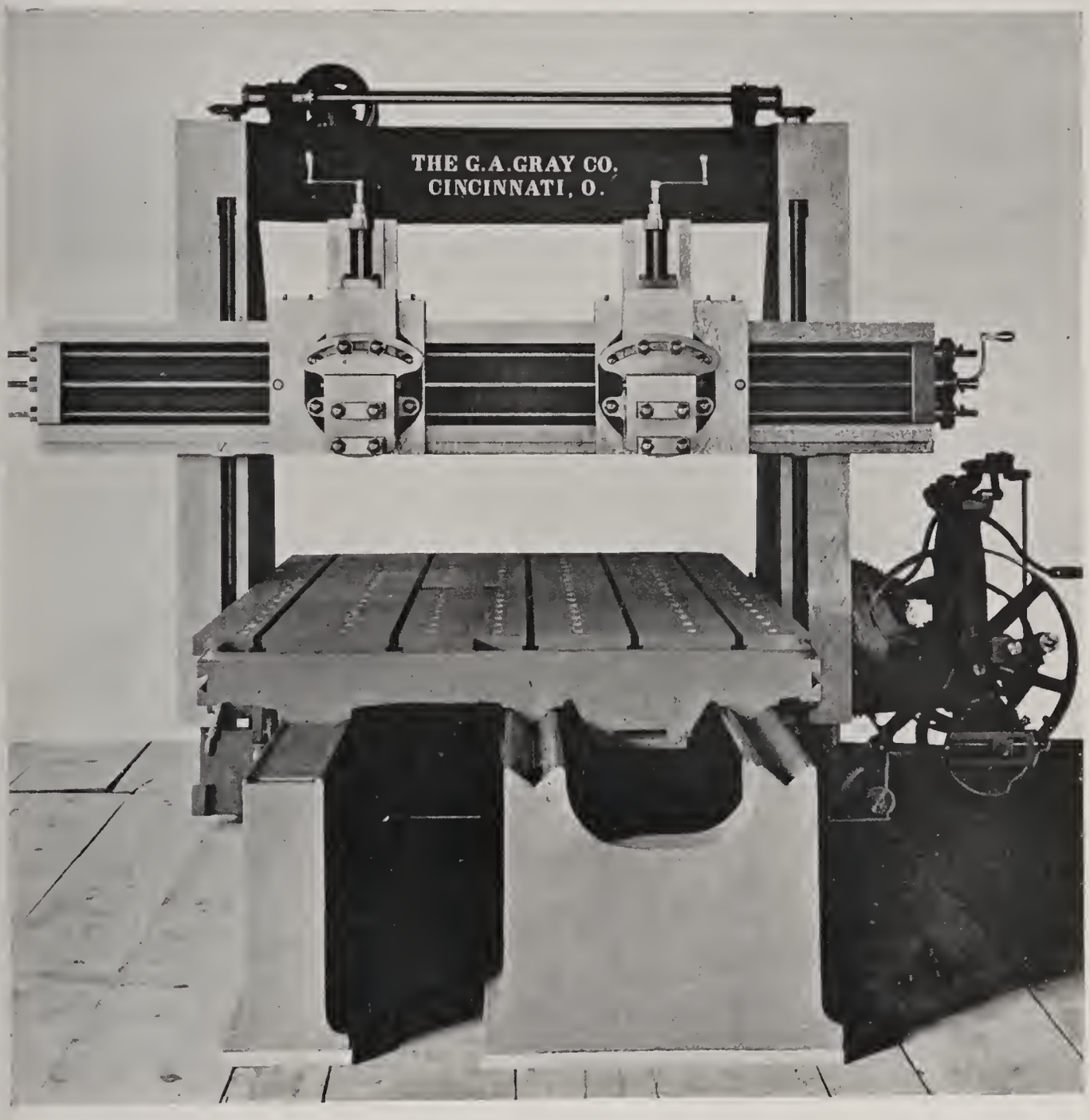

FIG. 6.

SPIRAL GEAR WIDENED PLANER.

The G. A. Gray Co., Cincinnati, Ohio.

height. This may be regarded as a special machine, and will be discussed under that head.

A criticism sometimes made in regard to modern planing machines is that too little attention has been paid to the transverse stiffness of the housings and the ability to resist

the pressure of the tool when taking a heavy side cut. The small width as compared with the depth of most planer housings seems to afford ground for this criticism, and some designers have proposed to put on heavy side flanges to resist the transverse pressure. These would interfere seriously with the convenience of the operation and with the arrangement of the feeding and adjusting mechanism. It must be remembered that in resisting side thrust the two housings and the top brace act as a unit, or rather as a braced structure. If the housings have proper depth of contact with the sides of the bed and are firmly connected at the top to a deep, well-designed top brace, the structure as a whole will have great lateral stiffness. This is well shown in Fig. 2. Especial attention should be given to securing the top brace firmly and rigidly to the housings.

The vertical ways on the face of housings should be wide, both for the sake of ample bearing surface for cross-rail and to give lateral stiffness to the housings themselves.

On small planers without side heads the ways need only come down near the table as in Fig. 1, but where side heads are used the ways should extend well below the table as in Fig. 2.

6. The Cross-Rail.

Thus far the discussion has been confined to the main framework of the machine, where the desired features are strength, rigidity, and large bearing surfaces. There still remains the mechanism for controlling the feed of the tool and the reversal of the machine. While strength and durability are of prime importance, adaptability and convenience must still be considered. In examining a machine tool one should ask first: 'Is it strong enough to do the work?' and second: 'Will it be a convenient machine to use, and will it give an output corresponding to its size and cost?'

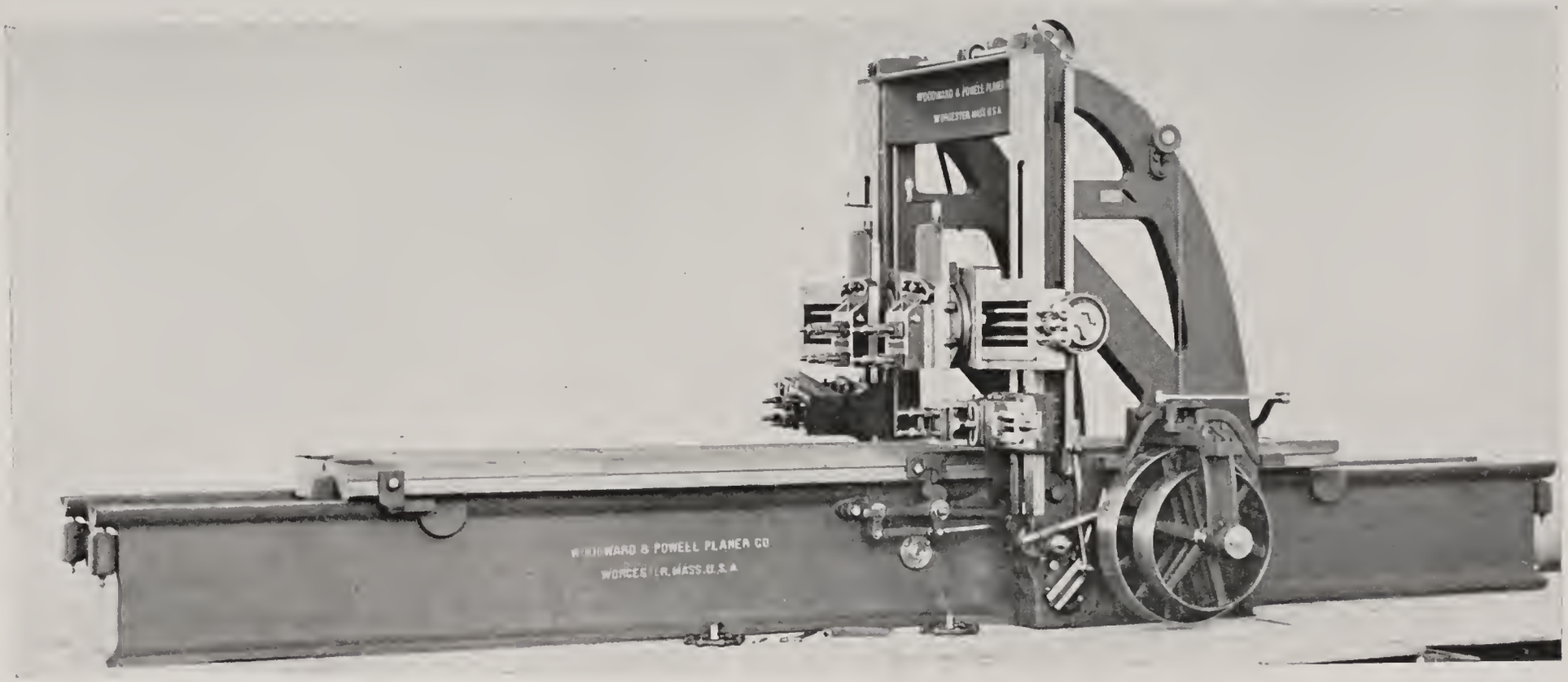

FIG. 7.

60″ × 48″ PLANER.

The Woodward and Powell Planer Co., Worcester, Mass.

The cross-rail, so-called, is designed to carry the tool head or heads, and to provide proper adjustments and feeds for the operation of the cutting tool. The cross-rail is raised or lowered on the housings by means of vertical screws, and is so gibbed that it may be firmly clamped at any height. In small planers, as in Fig. 1, the rail is raised or lowered by means of a horizontal shaft on the top brace, which is geared to both screws. This should have cranks at both ends, so that the rail may be adjusted from either side. Rails were formerly clamped to the ways on the housings by bolts and nuts on either side, requiring a trip around the machine and back every time a change was made.

Some of the modern planers have a clamping device for this purpose which may be operated by a convenient lever. Usually all planing machines with a capacity of 30 inches or over have means of raising or lowering the cross-rail by power. This consists of a separate shaft driven by the overhead countershaft and gearing with the horizontal shaft on the top brace, as may be seen by reference to Figs. 2 and 7. Fig. 7 also shows the means of counterbalancing the rail to ensure easy adjustment.

For strength and rigidity the rail should have considerable vertical depth and be well braced in the rear between the housings so as to approximate to a beam of uniform strength. The vertical depth gives it a good bearing on the ways, and prevents that twisting action so fatal to accuracy of cut. Some cross-rails have a parabolic brace at the rear; this is naturally located near the bottom rather than at the top of the rail, as it is there that the thrust of the tool is most felt.

The rail should extend horizontally on either side so that the tool head may be moved out and permit cutting the full width between the housings, even when swivelled at 45 degrees for an under cut. Fig. 2 illustrates this very clearly. When two heads are used it is good practice to allow an extra length on the back side of the machine, so that the further head may be set over out of the way and the nearer

head have the full range of width between housings. Fig. 6 shows this feature.

7. The Tool Head.

In discussing this important feature of the modern planing machine a distinction will be made between heads for small and large planers. Both types possess the same general adjustments, vertical, horizontal, and angular. Both are clamped to saddles which slide on the cross-rail.

The saddle in all American planers has a rectangular slide at the top and an angular slide at the bottom, as may be seen by reference to Fig. 5 and in many of the other illustrations as well. The square guide and gib at the top prevent the saddle from tipping forward under the leverage of the cutting tool. The angular slide at the bottom permits of easy adjustment for wear. The saddle is moved horizontally by the cross-feed screw, and should have a clamp to hold it rigidly in one position when taking a heavy side cut. Such a clamp may be seen in Fig. 1, which illustrates the usual type of head for small planers.

The tool post consists of a clamp with two bolts and hardened corrugated cheeks to support the tool. The arrangement is pivoted for lifting on the return stroke and is also swivelled to the vertical slide, that the tool may be so set as to lift away from the work on a side cut. The vertical slide is of the dove-tail type with an adjustable gib at one side, and is actuated by a left-hand screw. All modern planers are equipped with a power feed for this slide, driven by a splined rod and gears similar to those on a lathe.

A turn-table behind the slide makes it possible to take side cuts at any angle.

On larger machines such as that shown in Fig. 7 two heads are usually employed, and these are of a much more massive construction. Four clamping bolts are used instead of two, and more bearing is given behind the tool. The heads are

sometimes offset right and left to make it possible for tools to work close together.

A counter-balance is arranged for the vertical slides of very large machines, and an automatic lifting device prevents the heavy tools from dragging on the return stroke.

Both heads may be operated together in either direction, making practically two independent planers. The driving mechanism is all brought to the front end of the cross-rail within easy reach of the operator, so that without moving from his position he can control the vertical and the horizontal motion of either head.

Side heads are furnished, if desired, with most of the larger machines, but can be omitted if unnecessary. In general, planers having a capacity of 36 inches and upwards should have provision for attaching side heads when wanted.

The side head has all the adjustments of the ordinary head, and an extra long slide is provided for use on overhanging work.

8. The Gearing for Table.

There are two general methods of driving the table of the machine back and forth, viz., the spur-geared drive and the spiral-geared drive. The former is by far the more common on the sizes of planers generally used in shops, and is too well known to need very much description. A rack running lengthwise on the under side of the table is driven by a large idle gear, usually called the bull wheel. This in turn is driven by a pinion on the countershaft, which latter is connected by another pair of gears to the driving shaft of the machine. This general arrangement can be seen in Fig. 1.

In some machines the last set of gears are located outside the bed as shown in Fig. 5. Two pairs of gears are employed so that narrow, quick-running belts may be used on the driving pulleys. It would be difficult to shift wide, slow belts

promptly at the ends of the stroke. The large idle gear has been used to bring the gearing down away from the table, and because the teeth on a large gear are stronger and have more contact than those on a pinion.

For modern planing machines using self-hardening steels and taking heavy cuts the gearing should be unusually strong and stiff. This is accomplished by using cut steel rack and

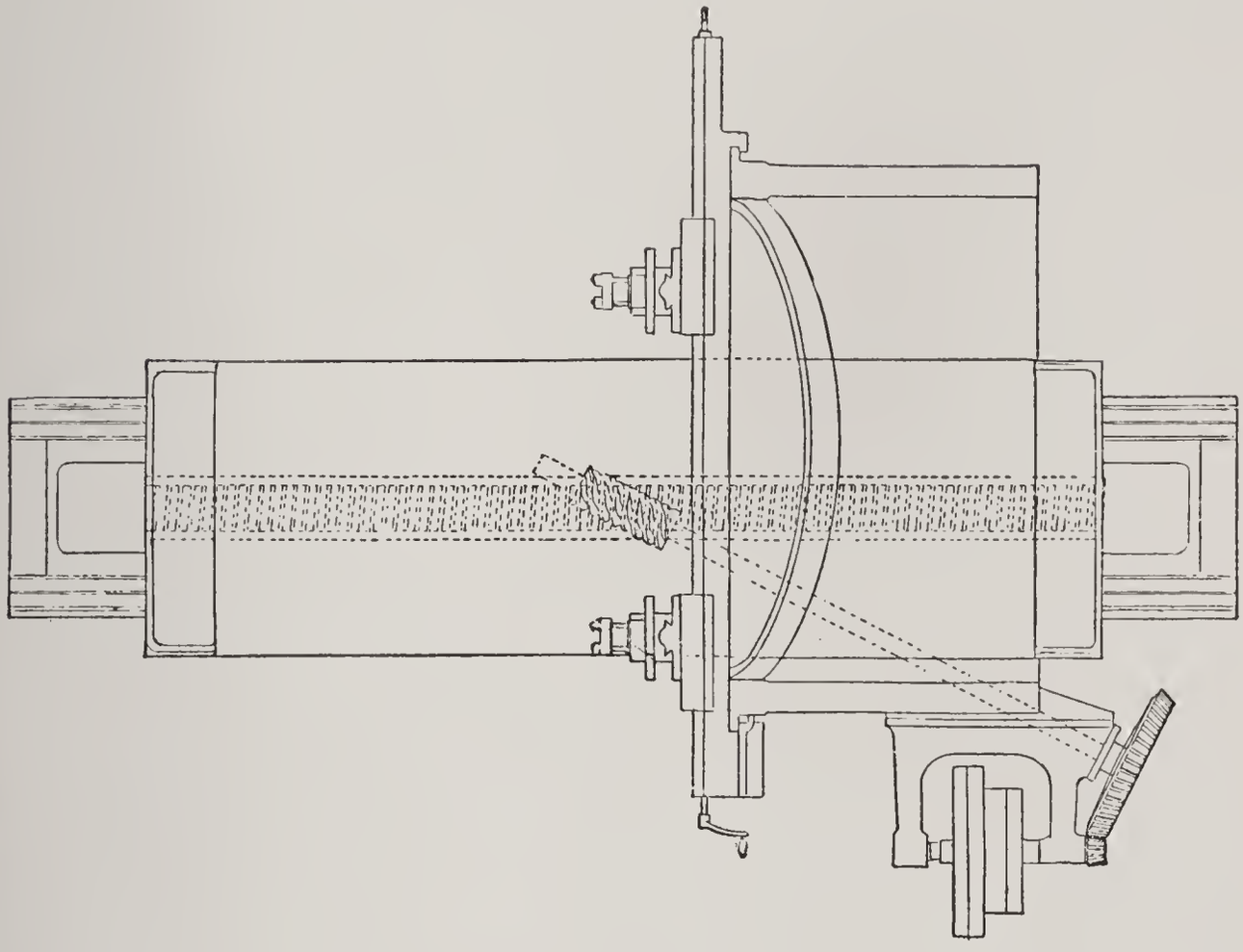

FIG. 8.

SPIRAL GEAR DRIVE.

gears and by having the journal boxes for the shafts inserted directly in holes bored in the sides of the bed casting. The shafts must be of large diameter and short between bearings, and the bearings themselves must be of good size and easily oiled.

There are several modifications of the spur-geared drive, the most common being the substitution of bevel for spur gears next the driving pulleys. This arrangement brings the driving shaft parallel to the bed, and permits of the planer

itself being placed with its line of stroke parallel to the overhead shafting. There is also some saving of width by this change.

The Whitcomb Manufacturing Co. substitutes a belt drive for one pair of gears and does away with the 'bull wheel.' Fig. 9 is taken from the catalogue of this company and shows the whole arrangement plainly. The makers claim for this drive several advantages, among which are comparative stillness and smoothness of action and the possibility of much

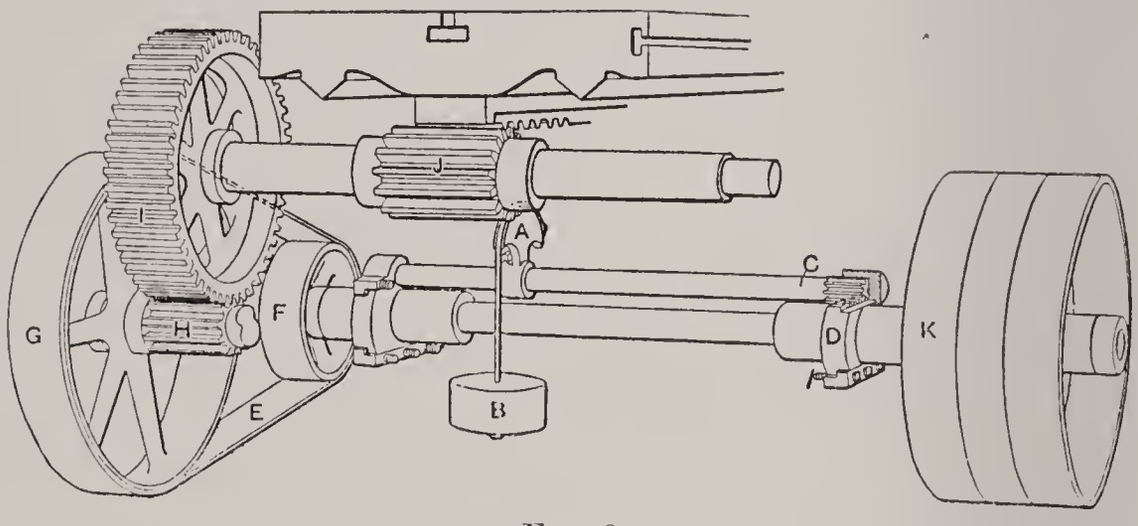

FIG. 9.

SECOND BELT DRIVE.

Whitcomb Manufacturing Co., Worcester, Mass.

higher cutting and return speeds than would be advisable with gears.

On large planers it is still necessary to use the 'bull wheel' in order to bring the second gear low enough to permit of the use of side heads.

The spiral-geared drive, originally introduced by the Sellers Company of Philadelphia, is used as a rule only on the larger sizes of planers. The usual arrangement may be seen in Fig. 8, which shows a plan view of the drive as applied to a widened planer. As may be seen in the cut, the rack is driven by means of a special pinion located on an oblique countershaft. This shaft is driven directly from the main pulley-shaft through a bevel gear and pinion. This

system brings the pulley-shaft in line with the stroke of the machine and permits the planer to be located with its length parallel to the overhead shaft; sometimes this is a distinct advantage.

The spiral pinion has a much larger number of teeth in contact with the rack than the spur gear (eight in the machine shown), giving greater strength and more smoothness in action. The simplicity of the spiral-geared drive is an argument in its favour. Actual use has shown it to give remarkable smoothness of action and a freedom from shock at reversals, accompanied by uniformity in length of stroke.

9. The Reversing Gear.

The general method of reversing the motion of the table is the same in all planers. Adjustable dogs or stops on the sides of the table engage a system of levers in such a manner as to shift the belts on the driving pulleys at either end of the stroke. One of the vertical driving belts is open and the other crossed, and each is provided with a tight and loose pulley. A shipper rod or lever is used for each belt as shown in Fig. 5. The details of the mechanism vary considerably in the different makes of planer, but consist for the most part of a cam plate with two rolls to actuate the shippers and a link connecting this cam to the shifter lever, this latter being pushed alternately forward and back by the dogs on the table. Figs. 1 and 5 show this quite plainly. The difference in speed between forward and return strokes is generally obtained by using pulleys of different size for the two belts.

One of the most annoying features of the older machines was the squealing of the belts at the instant of reversal, caused by the belts being moved simultaneously, one belt not leaving the fixed pulley until the other was partly on. This is done away with in the modern machines by the use of the cams, which move off one belt before moving on the

other. High speed and rather narrow belts are employed, as these can be more quickly shifted. In some machines the driving pulleys are located on opposite sides of the bed. The shifter lever is provided with a handle so that it may be operated by hand in setting work. There should be such a handle on each side of the machine. (See Fig. 6.)

It should also be possible to run the table entirely out from under the housings, without disturbing the dogs, when it is necessary to measure or examine the work.

The dogs on the table are usually provided with handles so that a wrench is unnecessary.

Some machines are fitted with a locking device in the shipper, so that it may be fastened with both belts on loose pulleys, and thus prevent accidents from starting up of the planer.

10. The Feed Mechanism.

The most usual device for operating the feed screws of the cutter head is a vertical rack, which moves up and down on the front side of the housing and actuates a train of gears by means of a ratchet motion. In Fig. 5 this rack can be seen with the reciprocating device at the bottom and the adjusting screw for changing the length of stroke.

In nearly all the illustrations a similar device is shown with some modification. (See Fig. 1.)

In the planers illustrated by Fig. 2 a splined vertical shaft oscillating in a horizontal circle communicates motion to the feed gears.

Either of these contrivances permits of a vertical adjustment of the cross-rail without disturbing the feed.

Where two heads are used each should have its vertical and horizontal feeds independent of the other, and it should be possible to feed at either end of the stroke. The side heads, if any, should also have power feeds independent of the other. All feeds should be adjustable when machine is in motion or at rest.

11. Widened Planers.

In a large establishment doing a great variety of work it is usually better policy to use standard machines of such different capacities as to accommodate any job that may come in. This because standard sizes of machines are designed as to strength and as to convenience in operation for certain sizes of work and will do that work better and more cheaply than any other machines.

On the other hand, it frequently happens that in a smaller establishment having a limited number of machines, work has to be rejected or done at a great disadvantage because it is slightly larger than the maximum capacity of planers or of lathes.

This state of affairs is an excuse for the widened planer and the gap lathe, and under such circumstances they will often repay a good interest on the investment. Fig. 6 has already been referred to as an illustration of a widened planer. This particular machine planes 38 inches in height, and has been widened by bolting the rear housing to a projecting cheek on the bed so as to plane 60 inches in width. The top brace and cross-rail being larger than the standard pattern, have deeper and stronger bracing on the back. The machine is then practically as strong as the standard 38-inch planer, and at the same time can plane the extra width mentioned.

It would be unreasonable to expect it to be capable of doing as heavy work as the regular 60-inch machine, but it can take the place of such a machine in emergencies. The planer shown in the cut has a supplementary table or slide in the rear of the main table which can be used to support heavy work.

Fig. 7 also shows a widened planer, the increase in width being but slight as it planes 48 inches in height and 60 inches in width. The increase of six inches on a side is obtained by widening the bed at the housings without changing the general design of the machine. Such a planer

would be nearly, if not quite, as strong as the standard machine, and would take the place of a 60-inch tool on wide work.

12. Open-Side Planers.

The so-called open-side planer, as its name implies, is a planing machine which has one side open for large work, one housing being entirely removed and the cross-rail depending for its support upon rigid bracing to the remaining upright. Fig. 10 illustrates this type of machine as built by the Detrick and Harvey Machine Co. of Baltimore, Md., the leading manufacturers of open-side planers in the United States.

The construction of the bed, table reversing gear and feed mechanism of these machines does not differ materially from that of ordinary planers.

As shown in the figure, very wide V's are used on this particular machine and special covers are provided to protect the ways from chips and dirt. The Sellers spiral gear drive is employed for moving the table, the large bevel gear showing plainly in the illustration.

The post or housing is made unusually deep, is braced laterally by projecting box flanges, and is tongued and grooved as well as bolted to the bed. It is readily seen that this member is exposed to a severe torsional stress from the pressure of the cutting tool and must be designed accordingly.

The cross-rail also, having no support at the rear end, is now in the condition of a bracket fixed at one end, and must be well braced. This is accomplished by a diagonal brace, as shown in the cut, bolted to the cross-rail and to the housing. A slide is provided on the housing for the end of the brace, to allow for vertical adjustment, but when the planer is cutting the brace is firmly clamped to the slide.

To still further stiffen the cross-rail it has a vertical projection running down the front of the housing and so arranged as to permit of clamping the two together when the

machine is in operation. This construction prevents the cross-rail from springing upward under a heavy cut and

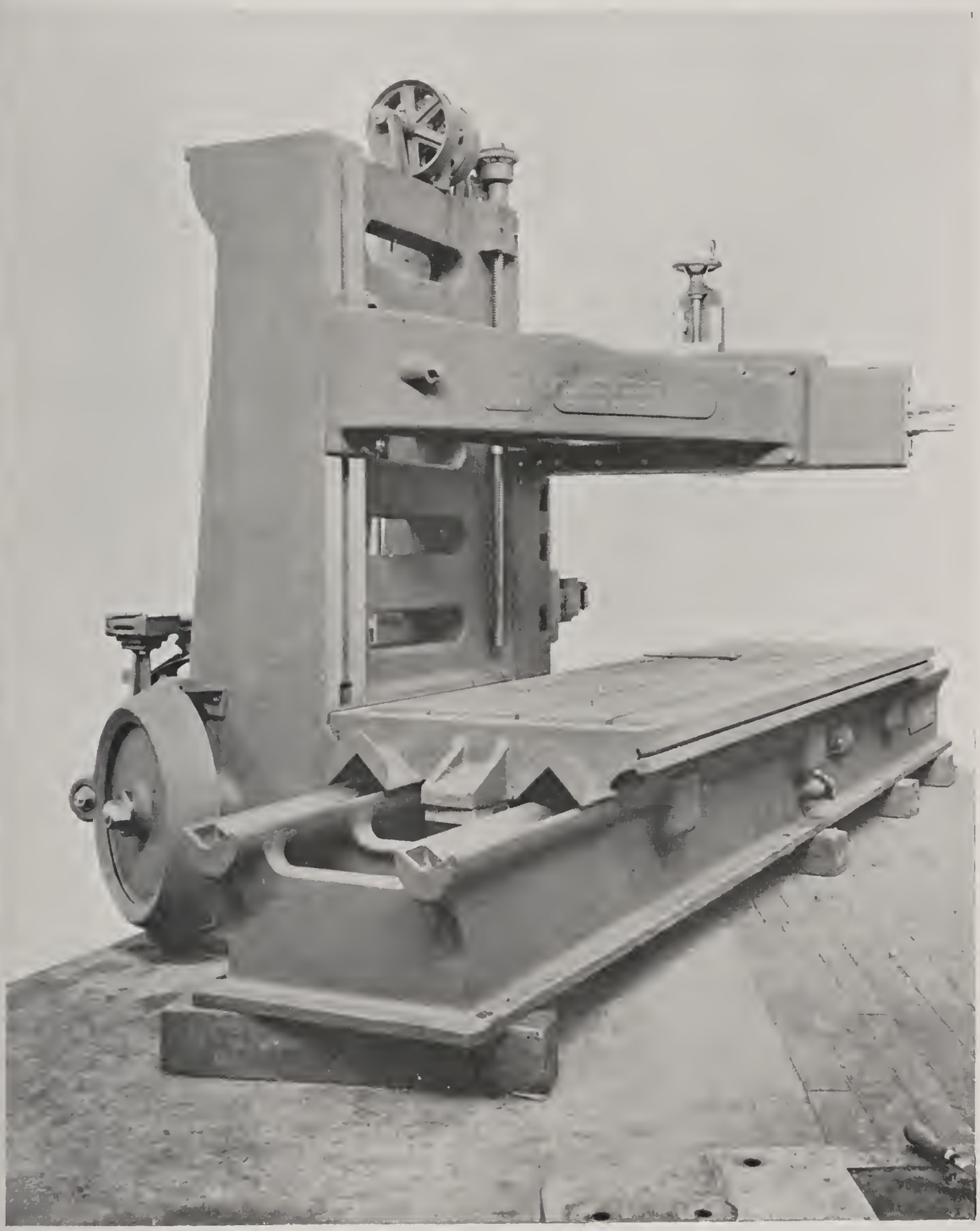

Fig. 10.

OPEN-SIDE PLANER—REAR VIEW.

The Detrick and Harvey Machine Co., Baltimore, Md.

makes the rail and housing practically one piece. A side-

head is mounted on a slide attached to this vertical leg and can be operated independently.

All the cutting heads have the same adjustments and feeds as on an ordinary planer, and the manipulation of the machine is much the same.

Each manufacturer must decide for himself whether it will pay him to use a machine of this kind. On one hand it may be said that the open-side planer is not so stiff and consequently will not take so heavy a cut without chattering as a standard planer of the same size. On the other hand, it is possible to do work on a machine of this class that could not be done at all on a standard planer of any reasonable capacity. Open-side planing machines have been found particularly well adapted to planing limited areas on large pieces, such as the junction areas of engine and machine frames and the joints in structural steel work. In this line, however, they have to contend with a notable rival, the so-called rotary planer of which more will be said in another place.

13. Combination Planers.

In establishments where the use of an open-side planer would be the exception rather than the rule, and such a machine could only be regarded as an emergency tool, a compromise is sometimes adopted. The Detrick and Harvey Co. build a planer which can be used with two housings or with one as conditions demand. The cross-rail is made of extra length, projecting several feet beyond the diagonal brace and supported at the rear end by an adjustable housing. The latter can be adjusted on its bed for different widths of cut and then clamped rigidly in position.

If the work is extraordinarily wide this housing can be entirely removed, the extension cross-rail can be slid back, and there remains an open-side planer. The unusual weight of cross-rail, braces, etc., in open-side and combination machines makes it necessary to give special attention to the

question of counter-balancing and power elevation for these parts.

The supplementary guide, which is a necessary feature of

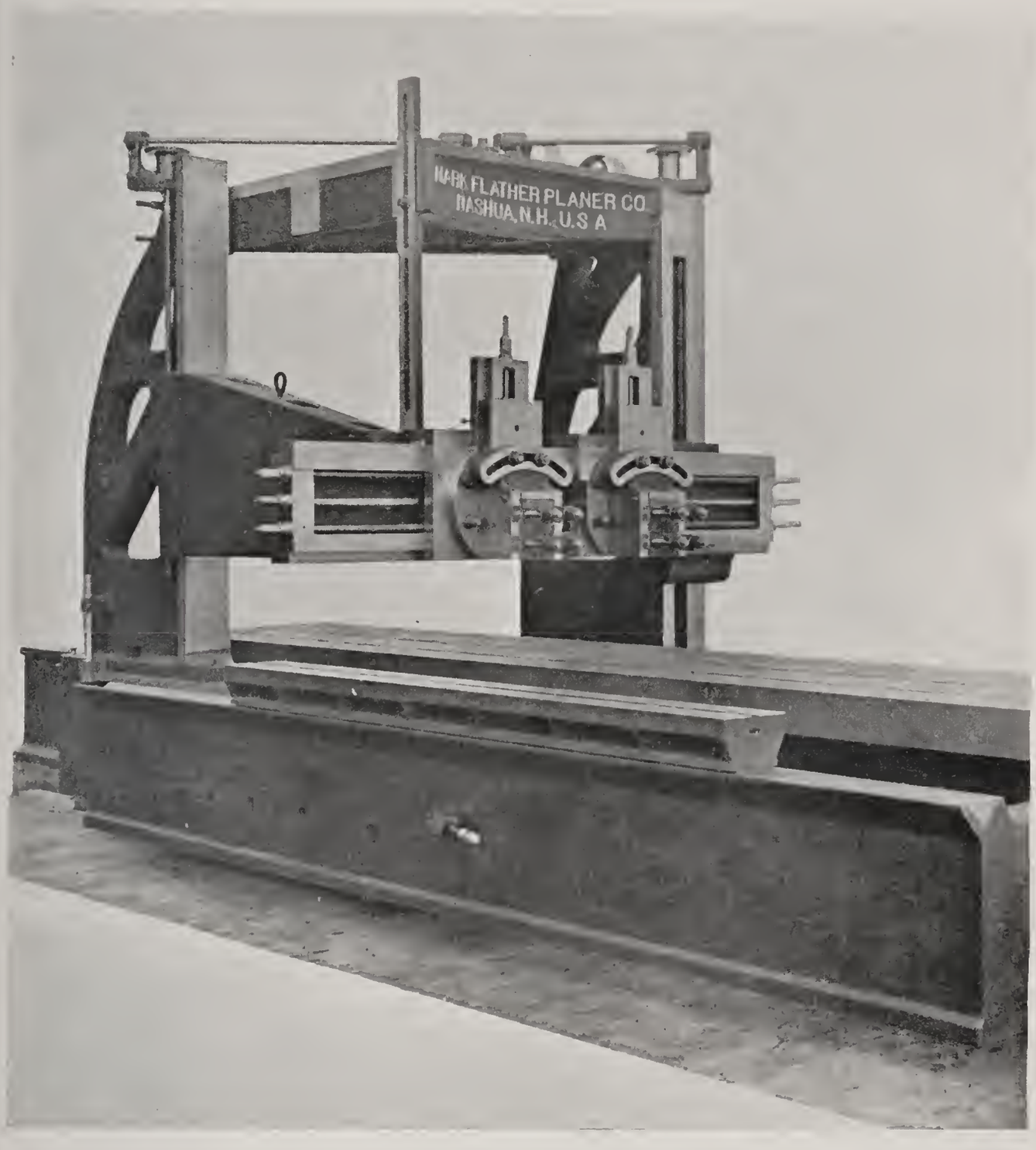

FIG. 11.

COMBINATION PLANER.

The Mark Flather Planer Co., Nashua, N.H.

extension planers of any type, usually consists of an I-beam supporting a train of rollers and a rail which is carried in turn by the latter. This rolling table, as it is called, can be moved to and from the planer, and forms an additional support for very wide and heavy work.

Fig. 11 shows a combination planer as built by the Mark Flather Planer Co. of Nashua, N.H. The illustration shows a standard planer converted into a partially open-side machine by running the rear housing back on the bed and interposing a stiff box casting between it and the cross-rail.

As will be seen from the cut, the top brace is made of such a form as to support the top of housing in either position. A supplementary vertical leg is used to assist in holding up the outer end of cross-rail and by an ingenious combination of bevel gears and telescoped shafts the same power-elevating mechanism is available in either position of the housing.

A 42-inch standard planer is so changed by this device as to plane a horizontal area of over 5 ft. each way on a piece of any width.

14. Cutting Speeds.

Table I.[1] shows the cutting speeds in feet per minute as recommended by various manufacturers. These vary from 15 feet per minute with the larger machines to 22 feet per minute with the smaller.

TABLE I

Cutting Speed in Feet per Minute.

Name of Maker.	Size of Machine in Inches.							
	24	30	36	42	48	60	72	
Detrick and Harvey,	...	20	18	17½	16	16	15	
Flather,	...	20	20	18				
Gray,	...	22	22	...	20			
Pond,	...	...	14	...	18	Actual Test		
Flather (recommended),	...	30	27	25	25	23	22	High Speed Steels.
Gray,	66	Actual Test						
American Tool Works,	60	,,	,,					

[1] See *Machinery*, New York, July 1903.

In general, cutting speeds are higher in the United States than in Great Britain or Germany, for all classes of machine tools. It is not unusual to find lathes cutting cast iron at a speed of 40 feet per minute.[1]

With the introduction of air-hardening steels there has been an increase of from one to two hundred per cent. in the speeds attained by lathes when cutting wrought iron or mild steel. It has been found possible to run continuously on work of this kind at a speed of 160 feet per minute. No such increase has been found practicable with planing machines on account of the intermittent nature of the cutting and the shock due to reversal. Neither the cutting tool nor the planer itself seems able to stand the sudden changes at such high speed. One firm of American planer manufacturers report that they are using speeds of from 35 to 40 feet per minute with small machines, and 28 feet per minute with larger size (42-inch). They do not, however, recommend speeds as high as these, taking into consideration the probable expense for repairs. As a result of their experience they recommend for air-hardening steel tools a speed of about 30 feet per minute when used in machines 30 inches and under, and from 25 to 27 feet per minute up to 48 inches. Above this latter size the speed should be reduced to 22 or 23 feet per minute.

The speed of return on American planers is from three to four times the cutting speed, being less on the larger machines.

15. Horse-Power.

The more extended use of the motor drive on machine tools has made it possible to determine conveniently and accurately the amount of power absorbed by the machine when cutting and when running light.

Perhaps the first tests of this kind reported were those

[1] See *Machinery*, New York, July 1903.

made at the Baldwin Locomotive Works in 1896 and published in the *American Machinist* of that year. Table II. gives a summary of the results for such planing machines as were tested.

The figures given for running the machines empty do not include the horse-power at the instant of reversal, but only the average horse-power required to run the empty table forward and back.

The power consumed by a 24-inch planer with 6-foot table as tested by the writer at various times averages about 1 horse-power, with a maximum of $1\frac{1}{2}$ horse-power. The amount of cast iron removed in the latter case was 25 pounds per hour. A 48-inch Pond planer running on regular work in a shop was found to consume 5·6 horse-power in cutting and 11·4 horse-power at the reversal when cutting about 15 pounds of cast steel per hour. A 36-inch machine of the same make required 4·3 horse-power when removing about 7·5 pounds of cast steel per hour. These planers were equipped with electric motors of 20 and 15 horse-power respectively.

TABLE II

HORSE-POWER OF PLANING MACHINES.

Name of Makers.	Size.	Material Cut.	No. of Tools.	Horse-Power Total Cutting.				
				Motor and Shaft.	Empty Machine.	Min.	Max.	Avge.
Sellers, .	62 in. × 35 ft.	Wrt. Iron	2	4·4	11·4	20·6	21·6	21·1
,,	62 in. × 35 ft.	,, ,,	2	...	5·8	23·0	26·0	24·5
Bement, .	24 in. × 13 ft.	Steel, .	2	1·95	4·3	...	...	8·0
Sellers, .	36 in. × 18 ft.	Wrt. Iron	2	3·2	4·3	...	...	16·7
,,	56 in. × 35 ft.	,, ,,	2	4·6	9·9	13·0	13·7	13·3
,,	56 in. × 24 ft.	,, ,,	2	4·56	6·0	16·0	17·7	16·8
Not given	36 in. × 12 ft.	,, ,,	2	2·7	3·0	11·3	13·8	12·5

Table III. is compiled from results published by *Machinery*, New York, in 1902.

TABLE III

Horse-Power of Planing Machines.

Size of Machine.	Material cut.	Cutting Speed. Ft. per min.	Number of Tools.	Horse-Power.			
				Of Motor.	Cutting.	Return.	Reverse.
10 × 10 × 20 ft., . .	Cast iron, .	18	3	30	26·5	23·6	42·9
8 × 8 × 20 ft., . . .	,, ,, .	18	3	25	16·0	14·8	28·2
60 in. × 60 in. × 12 ft.,	Steel casting,	21	2	...	10·0	14·0	16·0
28 in. × 52 in. × 6 ft., .	Cast Iron, .	22	1	3	3·1	3·8	4·4
36 in. × 36 in. × 12 ft.,	Cast Steel, .	17	2	...	2·15	2·22	11·0
36 in. × 36 in. × 12 ft.,	,, ,, .	22	2	...	2 85	3·06	11·0
72 in. × 72 in., . . .	Cast Iron, .	35	2	30	18·3	7·3	70·7

16. Electric Drives.

The driving of machine tools by electricity is a subject which will be discussed in a separate chapter, but some of the special modifications of motor driving for planing machines will be considered now.

If several machines of small or moderate size can be arranged in a group, the most economical method is to drive them all from one countershaft. One motor of a size somewhat less than the aggregate horse-power of the planers can be used to drive this shaft directly. This arrangement makes the first cost considerably less than for separate motors. The countershaft running at the same speed as the motor acts as a fly-wheel to furnish the excess of power needed at reversal; in fact, it is well to have a small fly-wheel on the counter to assist in the regulation.

Planing machines of 36-inches capacity and upwards requiring motors of more than 5 horse-power can best be driven by separate motors. In arranging a planer for the electric drive it is usual to mount the countershaft on brackets

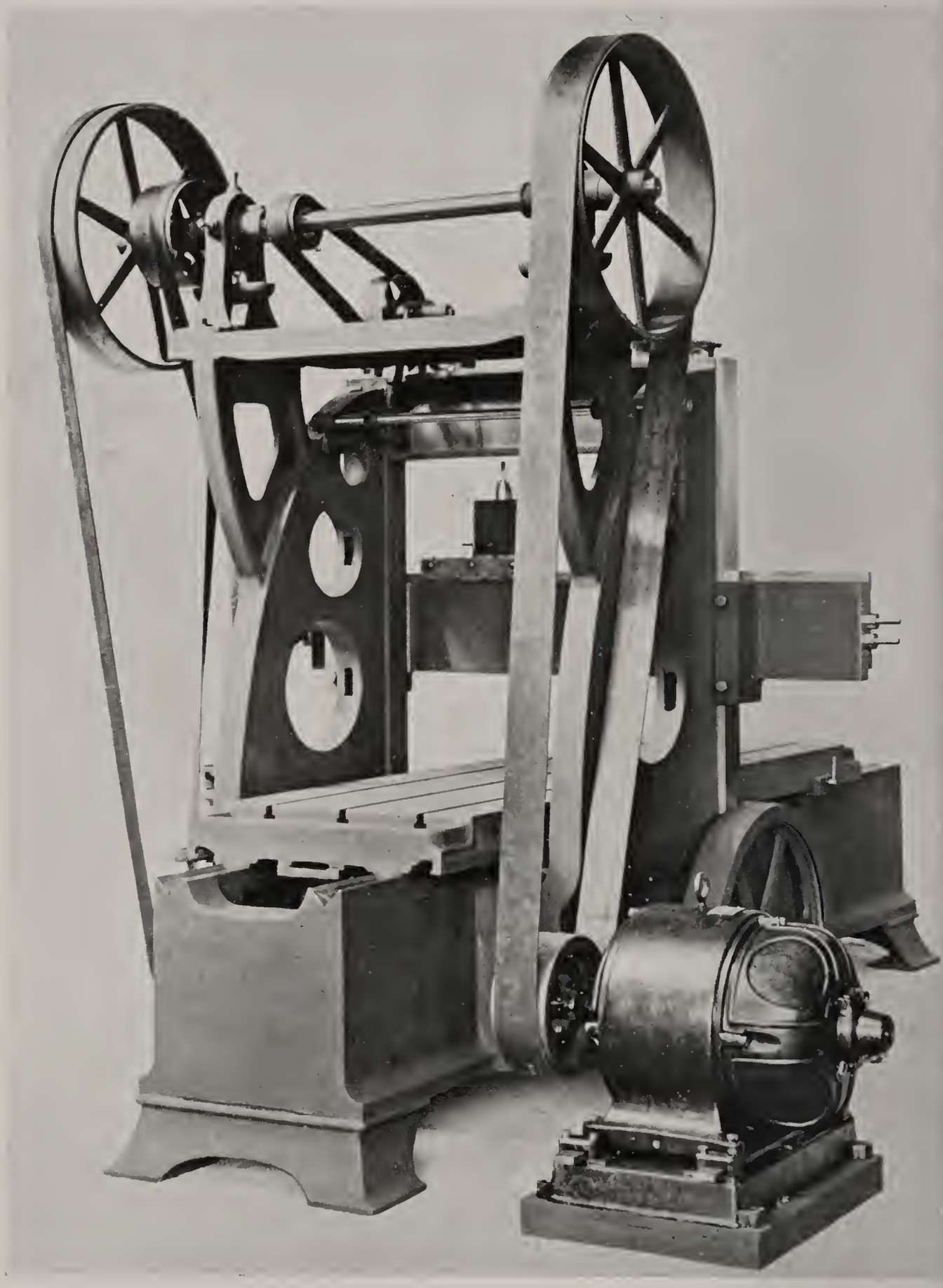

FIG. 12.

PLANER WITH ELECTRIC DRIVE AND BELT CONNECTION.

The G. A. Gray Co., Cincinnati, Ohio.

projecting from the top of the housing as shown in Figs. 12 and 13. Connection between the countershaft and motor is then established either directly or through gears, belts or silent chain.

The motor may be located on a bracket forming a part of the machine, and thus the whole be self-contained as is the case in Fig. 13; or the motor may be hung from the ceiling or bolted to the floor. Fig. 12 shows a very neat adaptation of the latter plan. The objection to the direct mounting of the armature on the countershaft is the necessity for using an expensive slow-speed motor.

Fig. 13 illustrates the application of the chain-drive to a planer, thus making the machine self-contained, and at the same time doing away with the slow-speed motor.

The Cincinnati Planer Co. have introduced a system of speed control for motor-driven planers whereby the cutting speed can be varied while the return speed remains unchanged.

A constant speed motor is bolted to a bracket on top of the housings and is geared direct to a countershaft, which in turn is bolted to the return motion. A second countershaft is used to drive the forward or cutting motion, and is geared to the first by a train which can be varied at will without stopping the machine. For example, the cutting speeds on one of their machines are 20, 25, 30 and 38 feet per minute, while the return speed is constant at 72 feet. The higher cutting speeds will be found particularly useful when employing air-hardening cutting tools on wrought iron or soft steel.

Mention should also be made of the reversing motor system of control introduced by the Electric Controller and Supply Co. of Cleveland, Ohio, which does away with belts entirely.[1]

The G. A. Gray Co. of Cincinnati recommend the following horse-powers of motors for planing machines under average conditions.

[1] See *Cassier's Magazine*, June 1905.

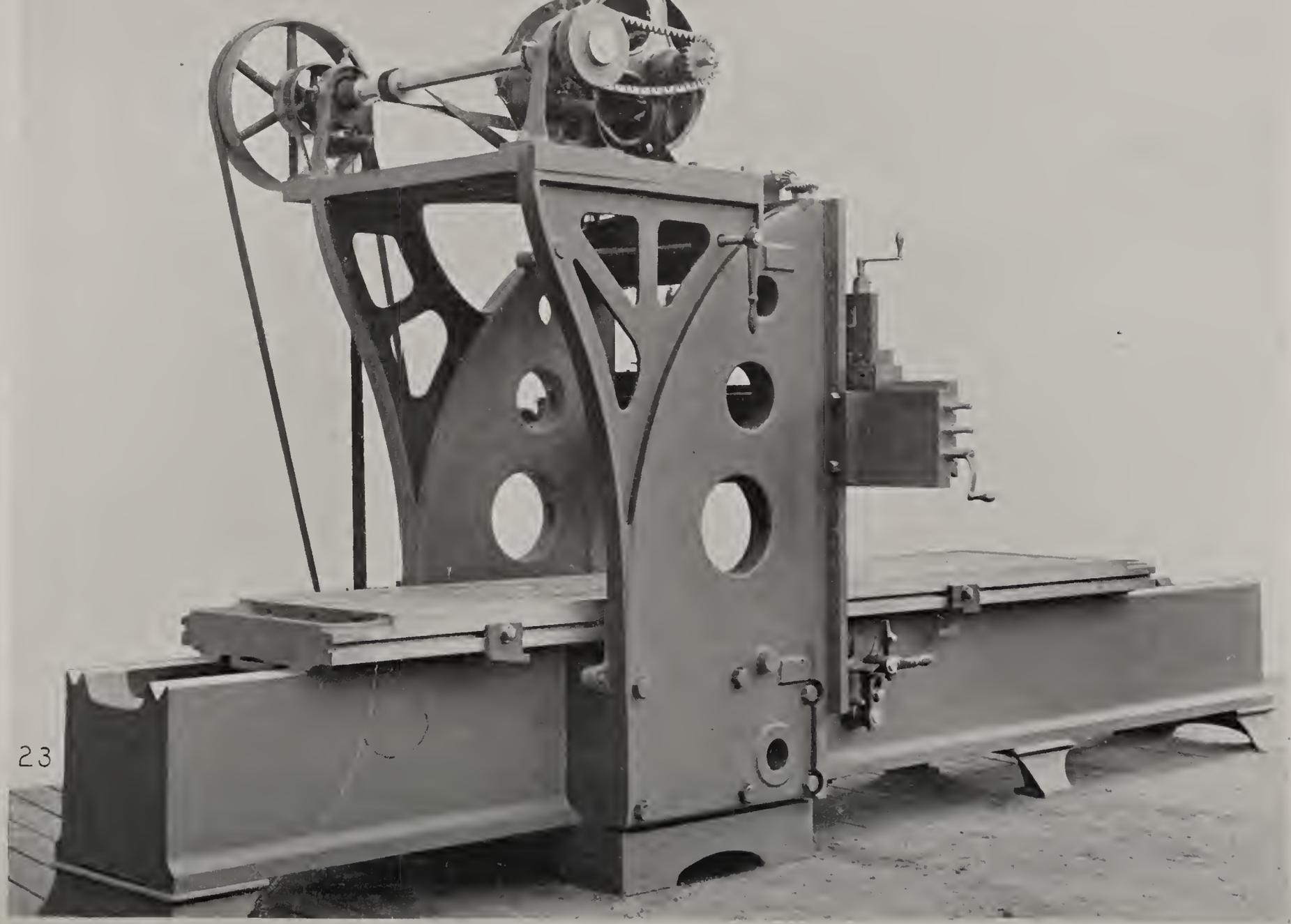

Fig. 13.

SILENT CHAIN DRIVE, WITH ELECTRIC MOTOR.

STANDARD SPUR-GEARED PLANERS.

Size, . .	22″	24″	26″	28″	30″	32″	36″
H.P. of Motor,	$2\frac{1}{2}$	$3\frac{1}{2}$	$3\frac{1}{2}$	4	5	6	6
Size, . . .	36″ Hvy.			42″	48″	56″	72″
H.P. of motor, .	8			12	15	15	25

The powers of some motors in actual use on planers are as follows :—

30 in. × 8 ft. Woodward and Powell, . . .	10 H.P.
36 in. × 12 ft. „ „ . . .	15 „
56 in. × 12 ft. Gray Co.	20 „
24 in. × 6 ft. Pond Co.	5 „
36 in. × 10 ft. „ „	5 „
60 in. × 25 ft. „ „	15 „

This shows some variation in the size of motors furnished for the same size of planer, due probably to a difference in the conditions. The motor should have an excess of power over that required for ordinary cutting on account of the 'kick' at reversal.

CHAPTER II

CRANK PLANERS, SHAPERS, AND SLOTTING MACHINES

17. Crank Planers.

As was noted in Chapter I., the distinction between planers and shapers is that of moving the work against the cutting tool or moving the tool against the work. Crank planers belong to the former class, but as they are in size and character of work more like shapers they will be considered in this chapter. Fig. 14 illustrates this class of machine, which, as compared with standard planing machines, is characterised by high speed and a short stroke. The machine shown in the cut has a capacity of 17×17 inches, while the maximum travel of the table is only 12 inches.

As its name implies, the crank planer takes the motion of its table from a crank instead of from a rack and pinion. The motion used is generally the Whitworth quick return or some modification of it, and the stroke is adjustable from zero to the maximum. The crank planing machine has this advantage over the standard machine, that the stroke is definite and exact and it is possible to plane right up to a mark without danger of over-running. It is somewhat stiffer and more accurate than a shaper on account of the table being supported its whole length.

Its accuracy and speed make it an excellent machine for tool and jig work.

The general arrangement is so much like that of the standard machine as to require no detailed description.

18. Shaping Machines.

Nearly all shaping machines are pillar shapers, so-called; that is, the mechanism is all supported by one pillar or column

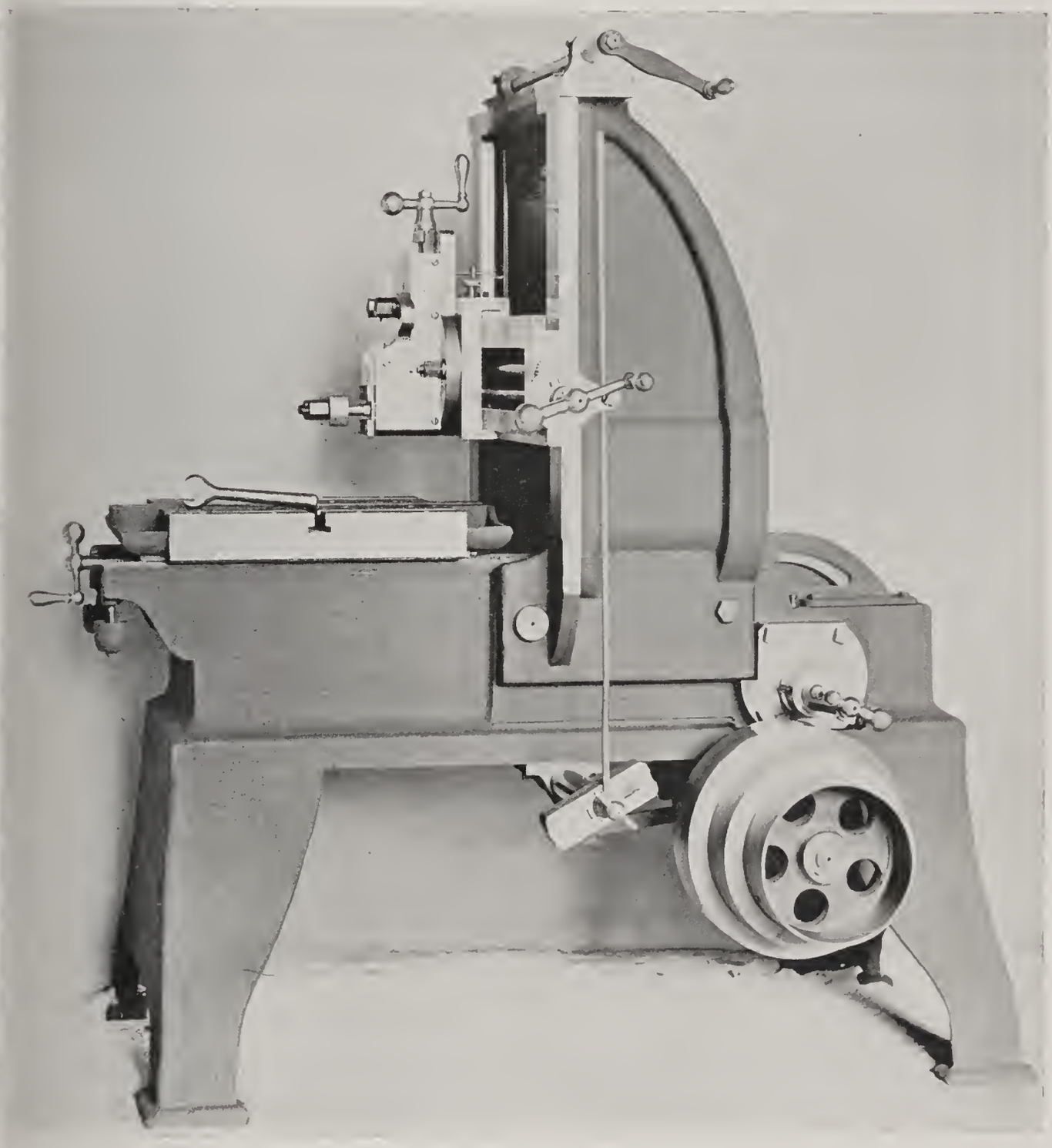

FIG. 14.

CRANK PLANER, 17 × 17 × 12 INCHES.

Whitcomb Manufacturing Co., Worcester Mass.

standing on a broad base. The principal elements of such a machine are: (*a*) the column above referred to, which carries all the moving or adjustable parts; (*b*) the ram or horizontal slide

for carrying the tool head; (*c*) the tool head itself; (*d*) the cross-rail which is adjusted vertically on the front of column and which in turn carries the table; (*e*) the table which holds the work and is fed horizontally on the cross-rail; (*f*) the gearing for driving the ram; (*g*) the feed mechanism for operating the table.

To these might be added that almost indispensable adjunct the vice, by which nine-tenths of all the work on a shaper is held.

19. The Column.

As may be seen by reference to the various illustrations in this chapter, the column of the shaping machine is a plain, rectangular cabinet with a broad base provided with tool shelves and with a closet for miscellaneous fittings.

The front of the column is provided with rectangular, vertical ways to which is clamped the cross-rail by means of gibbed slides. The top of the column carries gibbed ways for the horizontal slide of the ram. Various bosses and bushings support the running gear of the machine.

The cabinet form is particularly well adapted for shaper columns, and in fact for frames of all compact, self-contained machines. It is stiff to resist bending and twisting moments, and it is stable on the floor or the foundation.

It is of a convenient shape for the attachment of the vertical and horizontal slides, and the interior forms a safe and convenient location for the reciprocating mechanism.

The base should project enough to give stability, but not enough to interfere with the standing room of the operator. The front of the base usually projects more than the sides, and is planed true to permit of blocking up the table when heavy work is being machined, as shown in Fig. 15. This projection may be furnished with T slots as illustrated in Fig. 16, so that the table may be removed and large work bolted directly to the bed. As may be seen in these illustrations,

the cabinet has an opening directly beneath the ram so as to permit the splining of long pieces of shafting.

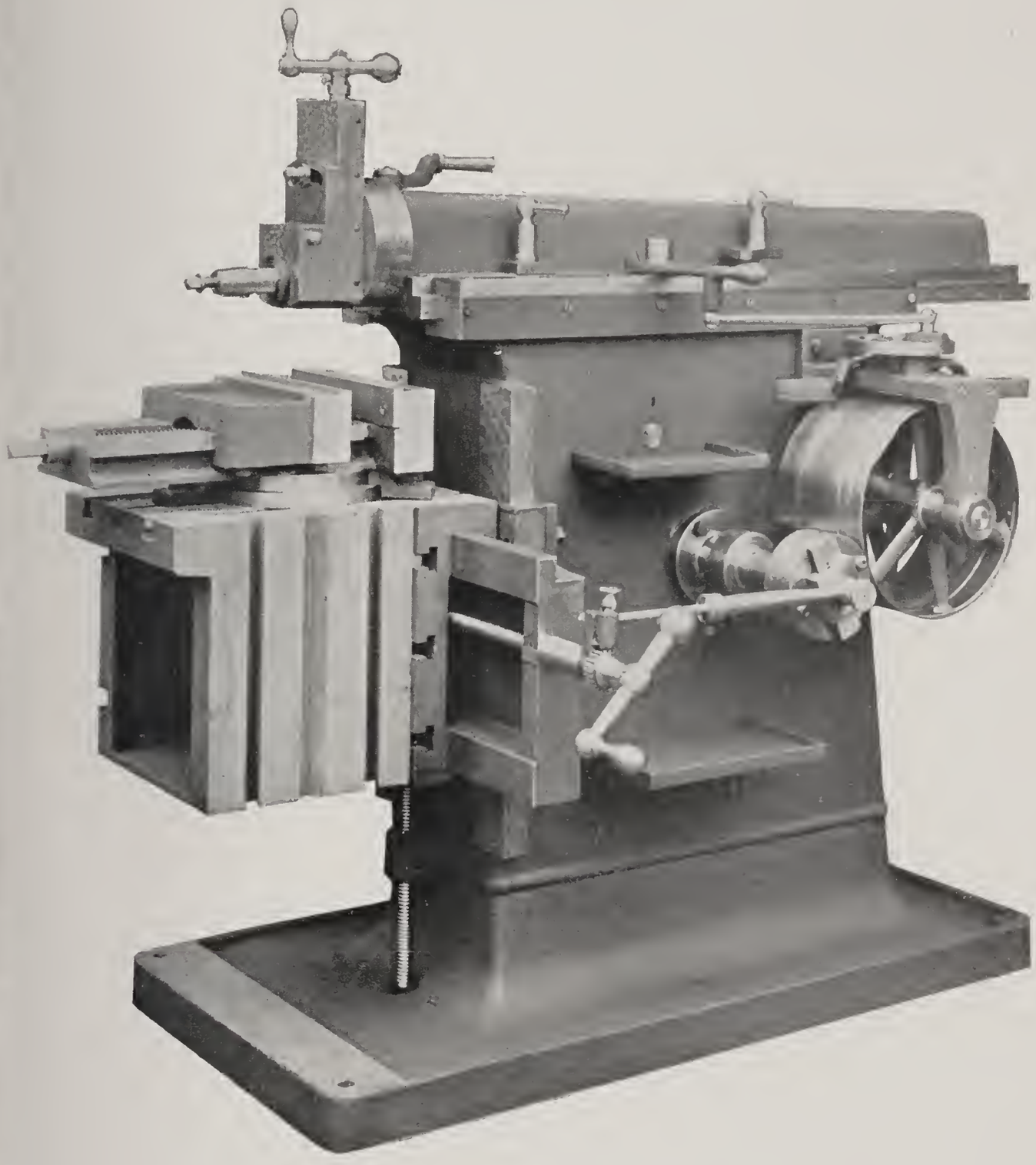

FIG. 15.

GEARED SHAPER.

The John Steptoe Shaper Co., Cincinnati, Ohio.

20. The Ram.

This is the working element of the machine, and on its strength and accuracy depends the value of the shaper as a machine tool.

As may be seen in the various illustrations, a hollow cylinder forms the basis of the design of the ram in modern shaping machines. In its ability to resist both torsional and bending strains this structure has no rival. The cylinder is more or less open on the under side to receive the driving elements, and is fitted with two rectangular wings running the whole length to serve as slides.

To do accurate work the ram must not only be strong in itself but must have long and wide bearing on the column. The ways in which the slides move must be rectangular and not dove-tailed, and must be so gibbed as to be capable of adjustment.

In some machines the ways project over the table to afford additional support in cutting.

In so far as this can be done without interfering with the location of work on the table, it is a good feature.

The ram is driven either by some form of crank motion having a quick return, in which case the machine is called a crank shaper, or by a rack and gear like the table of a planer, being then called a geared shaper.

When the crank motion is used it is necessary to adjust the ram forward and back on the driving mechanism so as to locate either terminal of the stroke. Some shapers are so arranged that this can be done when the machine is running. See, for instance, Fig. 16, where the hand-wheel and locking lever on top of the ram are a part of this adjustment. The exact length of stroke is sometimes shown by a pointer and scale on crank machines.

21. The Tool Head.

This element does not need any detailed description, being essentially the same as on a planer save that it has no horizontal feed motion. Like the planer head it can be swivelled to plane at any angle, and can be fed vertically by a screw and hand crank. In a few cases the head has a power

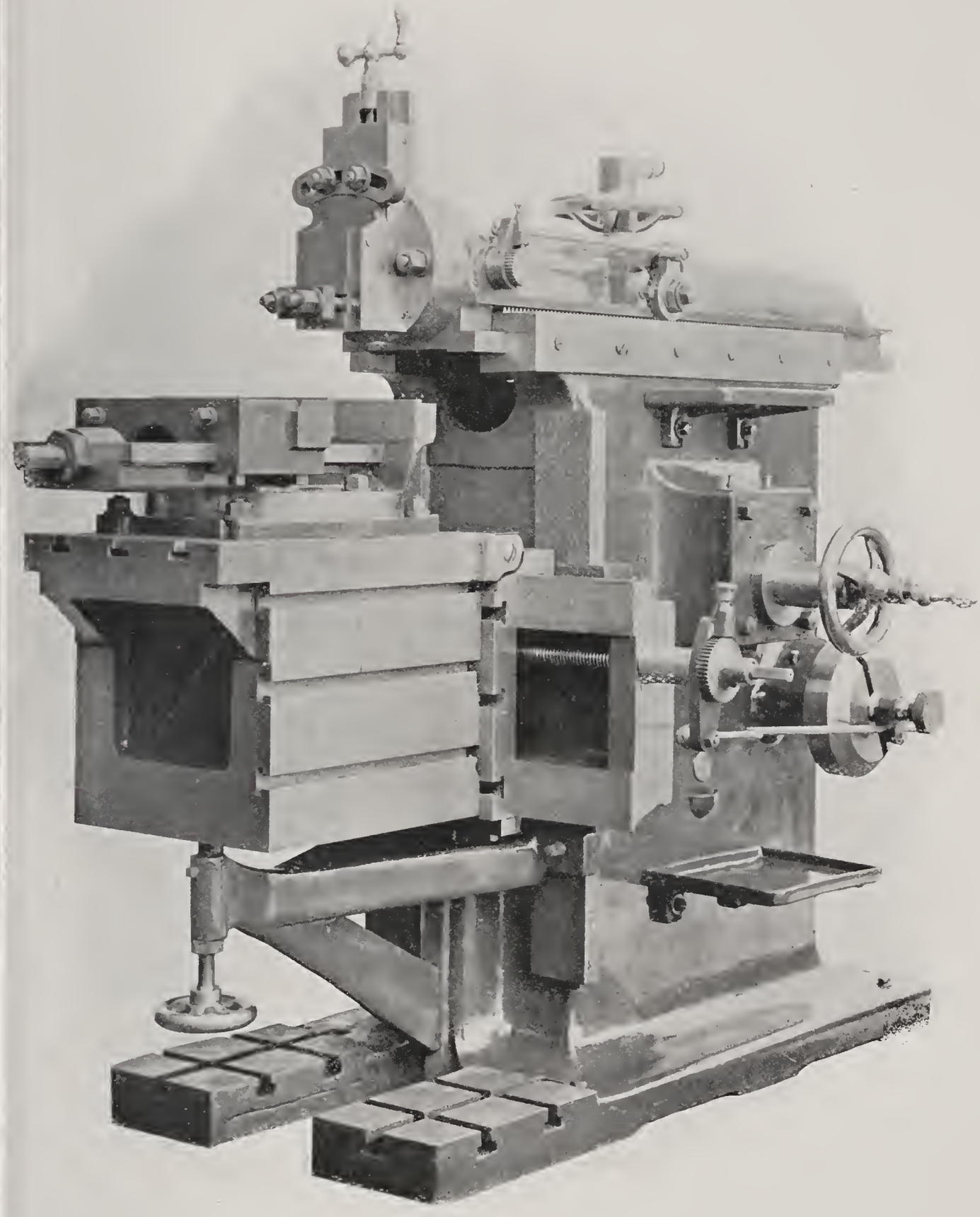

FIG. 16.

24-INCH SHAPER, WITH TILTING BOX-TABLE.

The Mark Flather Planer Co., Nashua.

feed as may be seen in Figs. 16 and 17. In the latter machine there is combined with the power feed an automatic stop which makes it safe to leave the machine running.

22. The Cross-Rail.

The rail is attached by rectangular gibbed sides to the vertical ways on the front of the column, can be adjusted at will and then clamped rigidly in position. The larger machines frequently have a power attachment for raising and lowering the rail such as shown in Fig. 17.

The machine illustrated in this latter figure has also an unusually wide bearing surface on the front of the rail giving a firm support to the table. The combination of rectangular and dove-tail ways serves the same purpose as in the cross-rail of a planer.

The cross-feed screw is also similar to that of a planing machine and is operated by means of a ratchet and pawl.

23. The Table.

A box-shaped casting, planed accurately square and fitted with T-slots on top and sides, serves to hold the work. This table is sometimes attached directly to the cross-rail as in Fig. 17, but is usually bolted to an apron or saddle which slides on the rail. The table can then be removed and work clamped directly to the apron when necessary.

The most serious fault of the shaping machine is the overhang of the table without adequate support, which permits of more or less springing under the pressure of the cutting tool. This, added to the upward spring of the overhanging ram, results in untrue work.

To remedy this difficulty additional supports are sometimes used. Fig. 16 shows a bracket underneath the table with an adjustable support for the outer edge of the latter. The bracket is attached to the cross-rail and rises or falls with it.

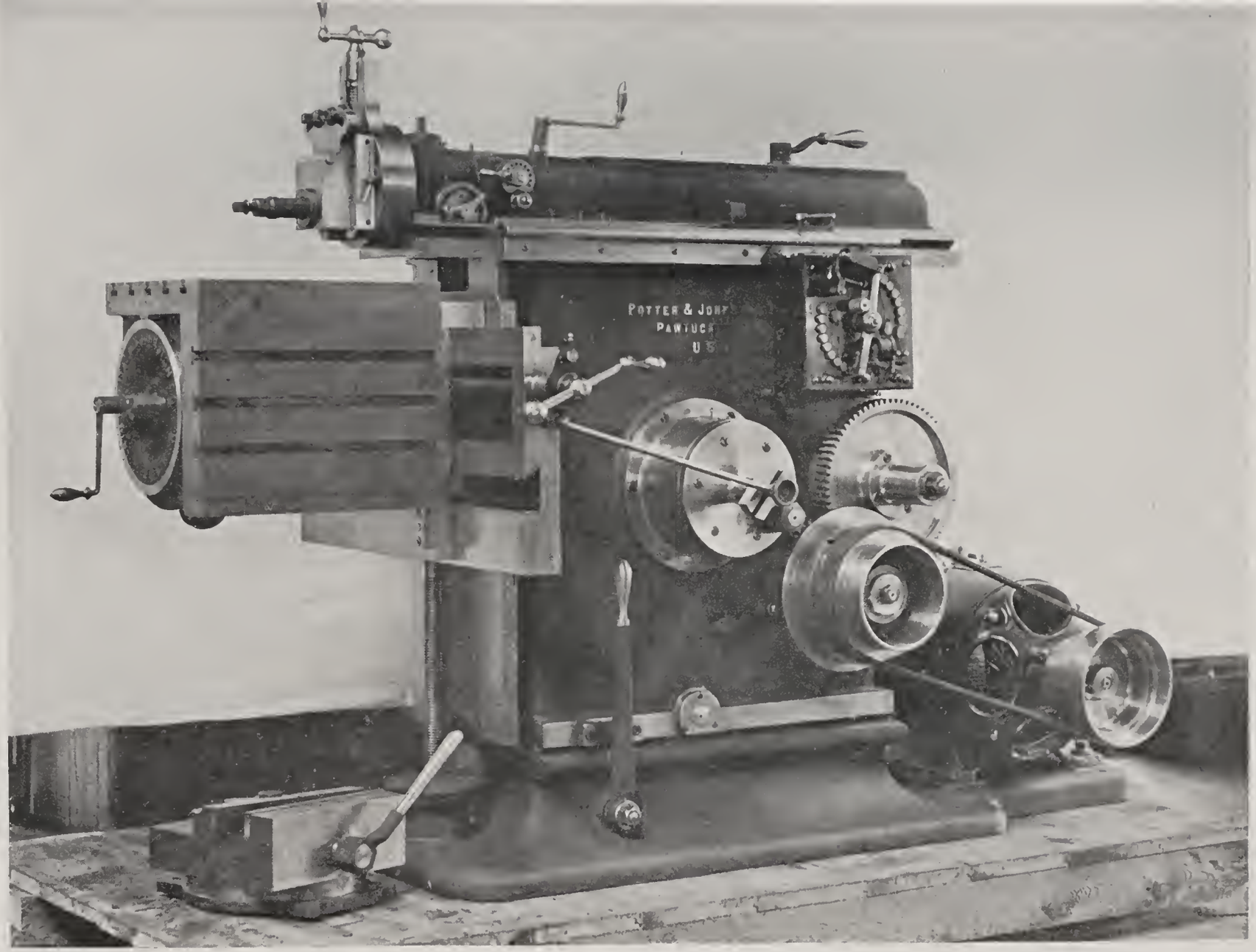

FIG. 17.

24-INCH CRANK SHAPER, WITH BELTED ELECTRIC DRIVE.

The Potter and Johnston Machine Co., Pawtucket, R.I.

The planed surface on the base underneath the table as seen in Figs. 15 and 16 may be made to serve a similar purpose.

Some builders provide an adjustable step which may be bolted to the under side of the table, and which has on its lower end a roll to travel on the planed surface of the base.

The ordinary motion of the table is the horizontal feed on the cross-rail.

Some makers provide, however, a swivel adjustment to the table which permits of using the power feed on the cross-rail to do bevel or angular work instead of swivelling the head. Fig. 17 shows one of these tilting tables.

24. The Driving Gear.

As has been already stated, shaping machines may be put in two general classes, those driven by crank motions, and those driven by racks.

These two kinds of drive have the same advantages and disadvantages as in planing machines. While most planers have a rack drive, and crank planers are the exception, the majority of shapers are driven by some sort of a crank motion. The most popular of these is the Whitworth 'quick return' in its various modifications. Fig. 18 shows this drive clearly, but in most machines it is concealed inside the column.

The adjustment for short or long stroke is obtained by sliding the crank pin, which drives the ram, in a diametrical slot on the crank. This adjustment is made without stopping the machine by means of a screw and bevel gears. The great advantage of the crank motion is in its positive length of stroke, making it desirable for short work. Its disadvantages are two:— (1) That the time of a long stroke is just the same as that of a short one, giving high cutting speeds on long strokes and low speeds on short strokes. This makes it necessary to introduce the complication of cone pulleys, and on larger machines the further addition of back gearing. (2) That the cutting speed is not uniform, being that due to a

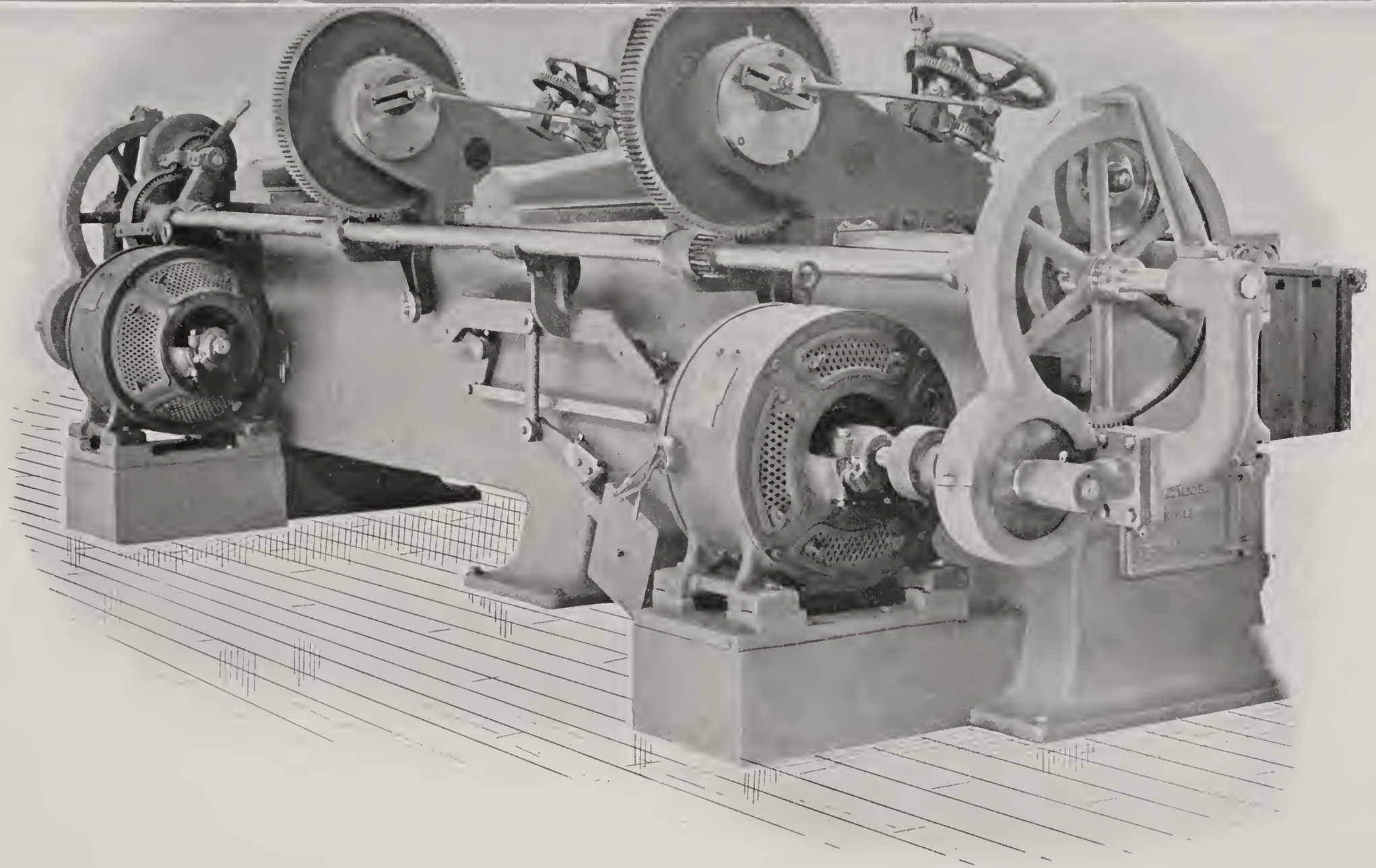

FIG. 18.

ELECTRICALLY DRIVEN TRAVERSE SHAPER, 18 INCHES × 14 FEET.

The Cincinnati Shaper Co., Cincinnati, Ohio.

crank movement, slow at the beginning and end, and fast in the middle. This defect has been overcome in some machines by introducing elliptic gearing in such a way that the irregularity of the gear motion neutralises that of the crank, producing a nearly uniform motion both on cut and return.

Geared shapers so-called are driven by racks on the under side of the ram and a train of gears similar to those used on planing machines. In order to permit of a clear passage for shafts and other long work under the ram, two racks are generally used, one on either side of the slot in the column. The shipping device is also similar in character to those used on planers. Two adjustable dogs on the ram move the shipping lever to and fro, or this latter can be moved by hand when desirable. The shipping lever actuates a cam or equivalent device whereby the belts are shifted on the pulleys, one at a time. Fig. 15 gives a particularly clear view of this mechanism.

The geared shaper labours under the same disadvantage as the planer in not having a positive length of stroke and in depending upon friction and inertia to control the motion.

On the other hand it has perfectly uniform cutting and return speeds under all conditions, and either end of stroke can be quickly located while the machine is running.

25. The Feed Mechanism.

In general, shapers have but one power feed, viz. the horizontal feed of the table. Since shaping machines are used mostly on small work and over small cutting areas, the necessity for power feed is not so apparent as on larger machines.

Many manufacturers will furnish a power feed for the downward motion of the tool head when it is desired. The machines shown in Figs. 16 and 17 have such a feed mechanism operated by the reciprocation of the ram, while other makers offer to attach the like when the customer desires it.

The cross-feed consists of a reversible ratchet on the feed-screw driven by a link and adjustable crank motion, these features being common to nearly all the machines shown. This, like the other adjustments, can be changed while the machine is in operation.

26. The Countershaft.

Crank shapers are usually driven by the ordinary countershaft with tight and loose pulleys. Geared or rack shapers have in themselves no provision for varying the cutting speed, and on small work or on brass or composition castings this is sometimes a disadvantage. To remedy this such shapers are sometimes furnished with a variable speed countershaft, such that its speed can be changed at the will of the operator by merely moving a lever.

27. Electric Driving.

The same considerations would guide one in arranging electric transmission for shaping machines and for planers. Several small machines of one type can be best driven in a group from one countershaft and by one constant speed motor.

When, however, it seems desirable to drive a shaper independently there are several combinations available. The most usual method for crank shapers is that illustrated in Fig. 17, where a constant speed motor is attached to the base of the machine and belted to the driving shaft over cone pulleys. The figure shows one geared speed reduction between the driving shaft and the machines to permit of the use of a high-speed motor. Another method, rather more expensive but more convenient for the operator, is to use a variable speed motor belted direct to the lower driving shaft of the shaper and to depend on electric speed control.

A third method does away with belts entirely, employing a variable speed motor geared to the driving shaft. In this latter case, if the shaping machine is of the geared type, the motor may be used to reverse the machine as has already been explained in the case of planers.

28. Traverse Machine.

The traverse shaper is radically different from the standard machine in many of its details, whether it carries one or two heads.

Strictly speaking, a traverse shaper is any shaper in which the cross feed operates the tool instead of the work. This change, however, usually entails others which differentiate the machine widely from the standard type.

An examination of Fig. 18 shows these differences clearly. The simple cabinet is replaced by a wide, box-shaped bed carried on two or more supports. Rectangular ways run from side to side at the top, supporting wide saddles or carriages which are fed across and back by feed screws.

These carriages support the rams and the entire reciprocating mechanism, this mechanism being driven by a feed rod similar to that on a lathe.

To the front of the bed are bolted the adjustable vertical ways which hold the tables. These can be located at will towards right or left of the machine, while the tables have the usual adjustments as in standard shapers. It is thus possible to locate the work at any part of the width of the machine and to operate on it with either head. Other attachments for holding work such as centres, cone mandrels, etc., can be fastened to the table or directly to the bed itself.

The convenience of this machine for handling some kinds of work is apparent. It is in principle an open-side planer with a stationary table and travelling housing, and should be particularly useful in finishing spots on limited areas on comparatively long and unwieldy pieces.

29. Open-Side Shaper.

One serious objection to the ordinary shaper is the overhang of the ram in taking long cuts. To overcome this difficulty in a measure, one firm manufactures an open-side machine in which the ways are one above the other and extend for a considerable distance over the table.[1] The housing, as it is called by the makers, by reason of its shape and location, affords considerably more support to the ram than is usually the case. Thus in the machine described, when the tool is out to the end of a 24-inch stroke the end of the ram is flush with the end of the housing. The driving mechanism is of the gear and rack order. The table differs in a marked degree from the ordinary shaper table, being more like those used on milling machines. The apron is expanded into a bracket or knee, raised and lowered by a screw at some distance from the column, while the table is flat instead of box-shape and has a wide bearing on the knee. Contrary to the usual practice, the slots in the table are transverse to the stroke. This seems the better way.

It would seem that both the ram and the table in this machine would be stiffer and more accurate than those ordinarily in use, especially on long cuts.

30. Draw-Cut Shapers.

The standard shaping machine when taking a cut tends to spring cross-rail, apron and table away from their several supports and to open all the joints. The draw-cut shaper shown in Fig. 19 removes this difficulty by pulling instead of pushing the cutting tool, thus bringing the table and its connections into compression rather than tension. This reversal of the motion of the ram has the further advantage of causing the tool to spring away from rather than towards the work, when cutting, on the principle of the spring tool.

An abutment can be placed between the work and the

[1] The Fox Machine Co., Grand Rapids, Mich.

frame of the machine, so that the pressure exerted by the tool may be transmitted directly to the frame.

The ram is driven by rack and gear, as may be seen from the figure.

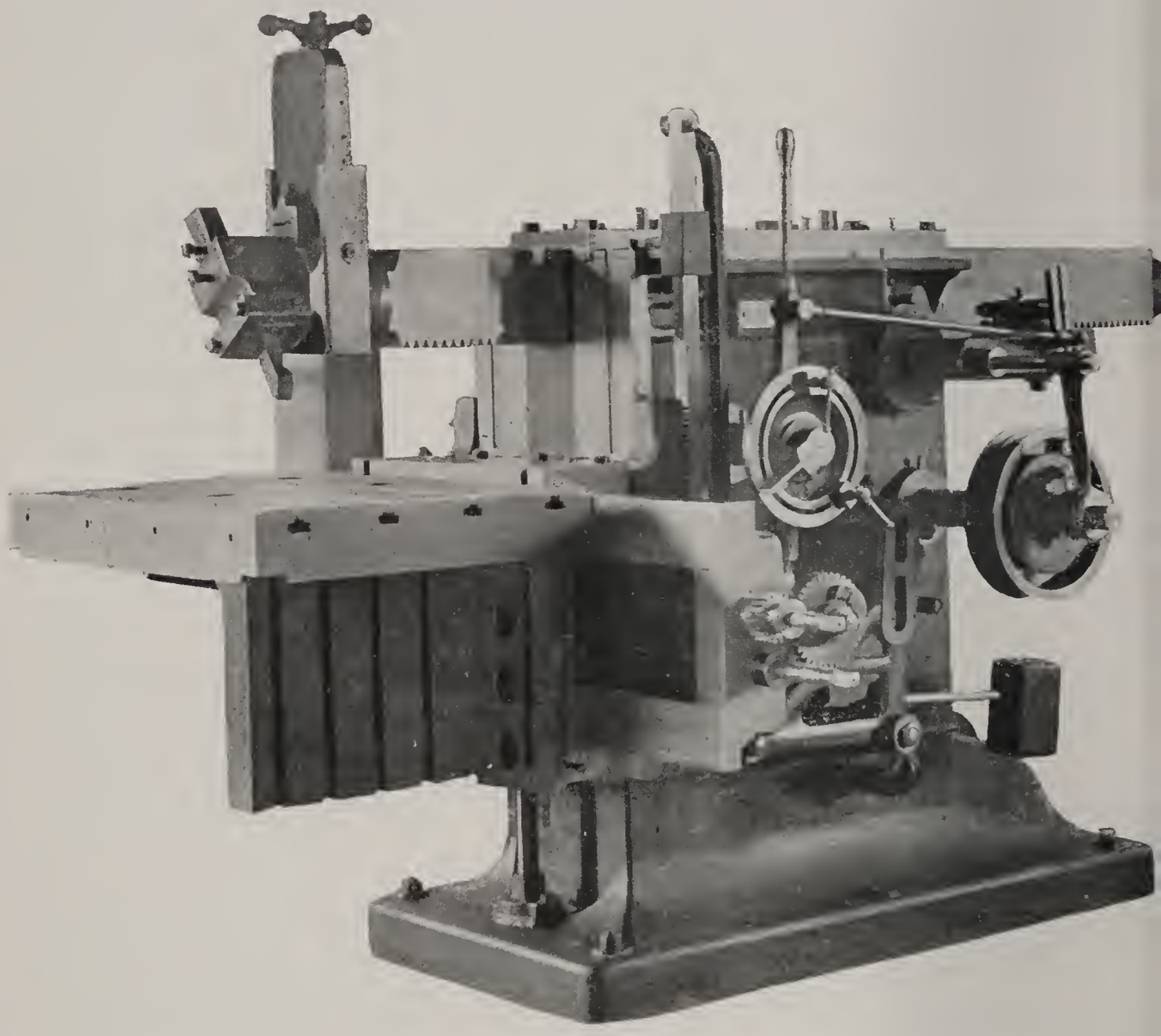

FIG. 19.

MORTON DRAW-CUT SHAPING MACHINE.

The Morton Manufacturing Co., Muskegon Heights, Mich.

In criticism of this machine it may be said that the pulling action tends to spring open the joints in the tool head. The machine illustrated shows a complication of mechanism which would prejudice most buyers against it at first sight. A comparison of the illustration with those before referred to will make this clear. If the advantages of the draw cut could

be obtained without so much additional mechanism the result would be more satisfactory.

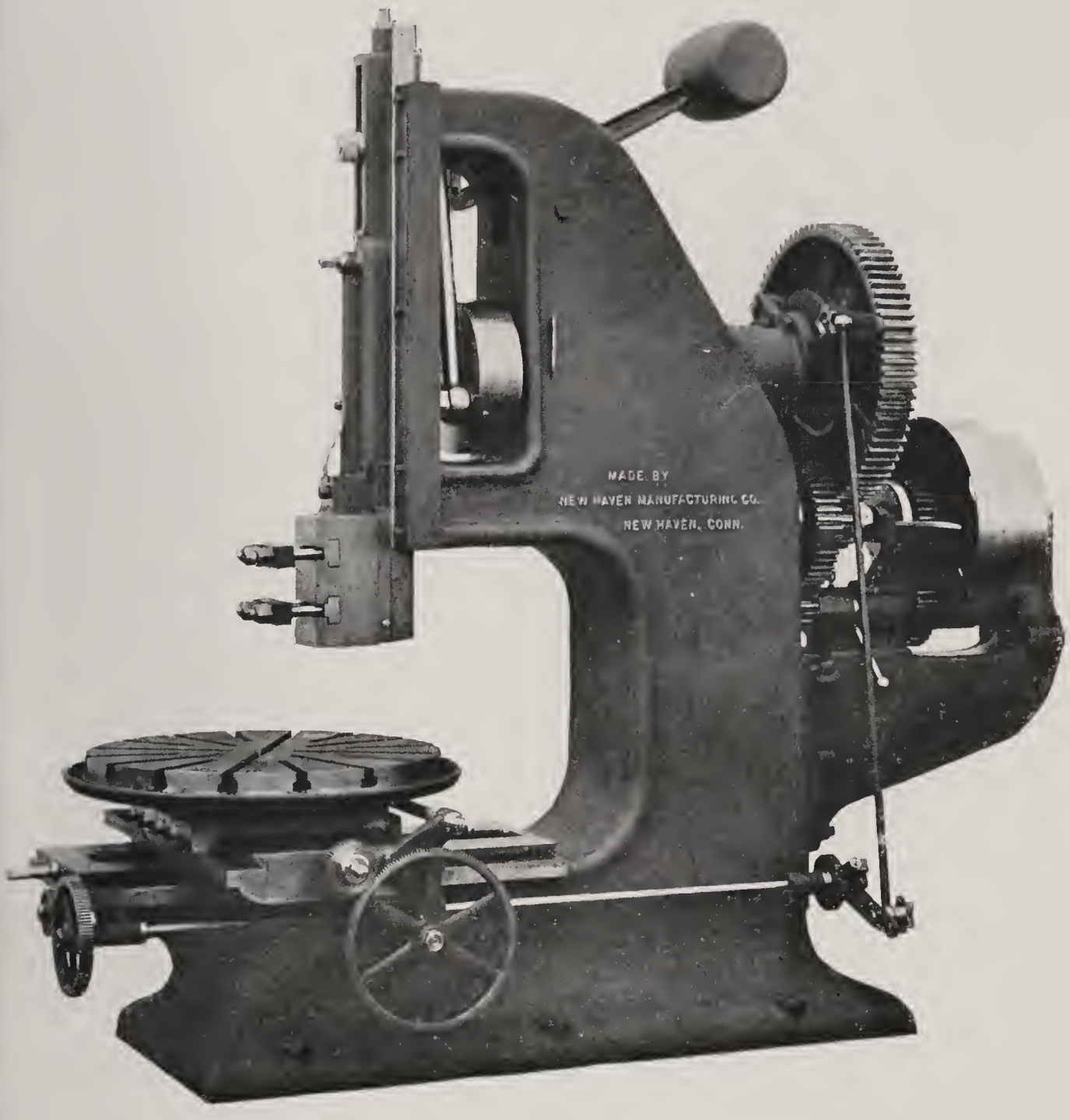

FIG. 20.

10-INCH STROKE SLOTTER.

New Haven Manufacturing Co., New Haven, Conn.

31. Slotting Machines.

A slotting machine may be described as a shaper with a vertical ram, the table remaining horizontal. Fig. 20 shows the ordinary type of frame and arrangement of parts for this

class of machines as built in the United States. Although of comparatively short stroke (usually ranging from 10 to 24 inches), slotting machines are intended for heavy work, are back-geared and have frames capable of withstanding great pressures.

As may be seen by reference to the cut, the frame is of a box-section and similar to the frame of an upright drill, but much heavier.

The ram has a long bearing surface on the frame to prevent springing, and is counterbalanced by a lever and weight. It is driven by a crank and pitman and has two adjustments; one is an adjustment of position to locate terminals of stroke; the other an adjustment of the slotted crank to change the length of stroke. The crank is driven by the Whitworth quick return motion with a ratio of about 3 to 1. In Fig. 20 the machine is driven by a cone of two steps with or without back gears. In other machines of this class it is driven directly by one large gear and a cone of four steps. The tool head is heavy and equipped with a double clamp tool-holder. The tool block must always have a relief motion for the return stroke.

The plane of the table being at right angles to the cutting motion, it is possible to secure circular as well as straight feeds.

Accordingly the tables of slotting machines have three power feeds, longitudinal, transverse, and rotary.

The platen of the machine moves longitudinally on the frame, the saddle or cross-slide moves transversely on the platen, and the circular table can rotate on the cross-slide. Any one of these parts can be clamped rigidly to its neighbour, and by a combination of any two of the motions oblique or irregular outlines may be cut.

The very general use of the slotting machine for finishing the profiles of irregular castings necessitates this entire freedom of movement in the table, and also demands great strength and rigidity of construction.

The illustration shows plainly how well these requirements have been met. The details of the feed mechanism are so clearly indicated in the cut as to call for no special description.

The convenience of these machines in operation is enhanced by the fact that all the adjustments are within easy reach of the operator when standing in one position.

The range for various sizes of work is usually proportional to the stroke of machine. The diameter of table is from two to three times the stroke, while the maximum diameter of work is from four to six times the stroke.

32. Key-Seating Machines.

Machines which are specially designed for cutting the inside rather than the outside surface of the work belong to a different class and may be grouped under the above head.

Although most generally used for splining the bores of wheels, gears, and cranks, they may be applied to any inside work with success.

Fig. 21 illustrates a so-called draw-stroke slotting machine which belongs to this class. On account of the limitations of the work the design differs materially from that of the ordinary machine.

The fact that the tool must work inside holes of a certain diameter precludes the use of a large ram, and a cylindrical cutter bar is substituted which reciprocates vertically through a hole in the table.

This slenderness of the bar makes necessary the upper bearing and the radial arm shown in the illustration.

The pulling or draw-stroke is used in this class of machines to prevent springing and chattering of the cutter bar.

This stroke is applied to large machines and possesses the advantages which have been discussed under the head of draw-stroke shapers. The cutter bar has a uniform cutting

motion with a quick return, and an automatic movement of the table relieves the cutter on the up-stroke. The table has

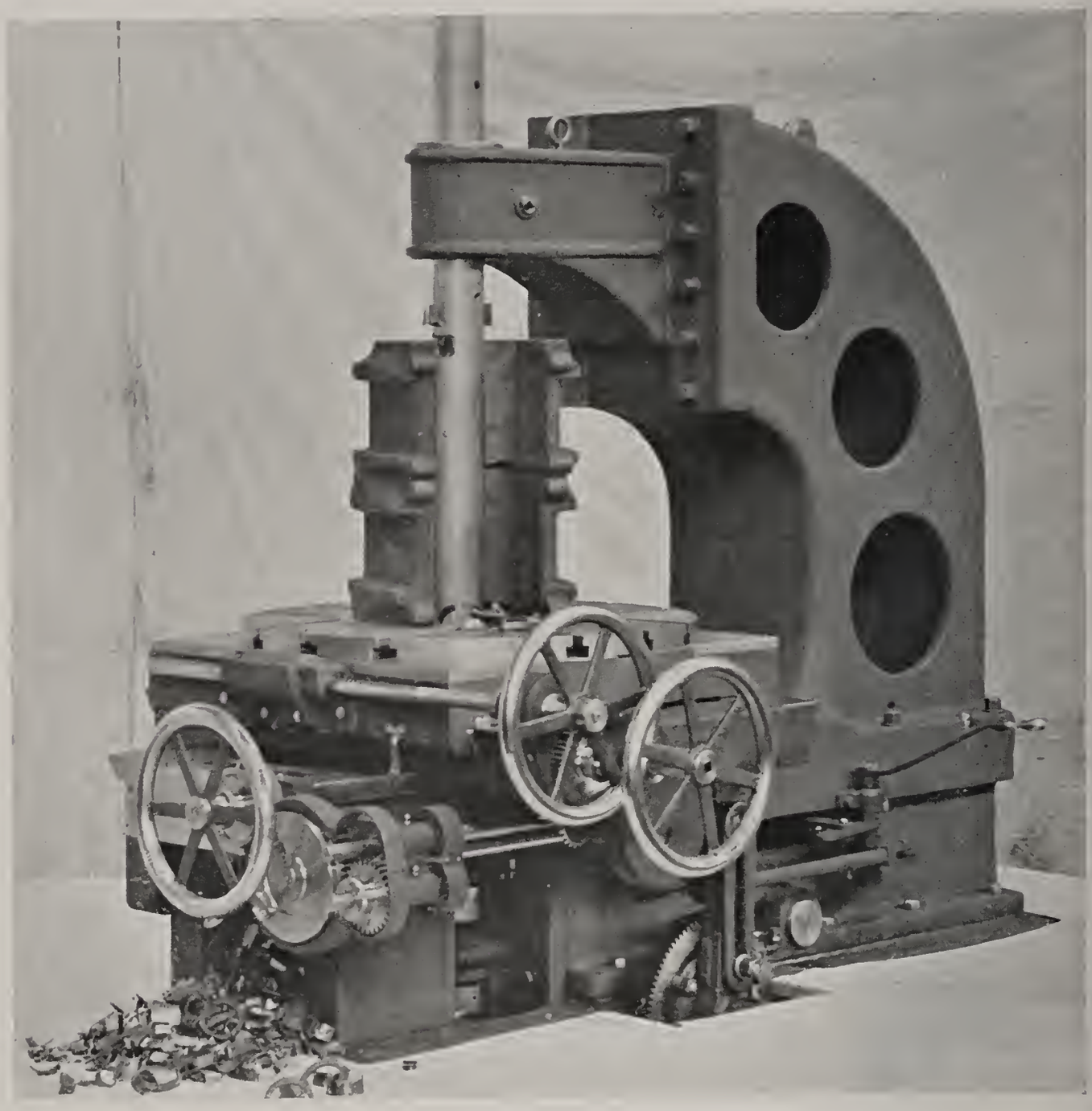

FIG. 21.

LARGE DRAW-STROKE SLOTTING MACHINE.

Baker Brothers, Toledo, Ohio.

the same motions as in the ordinary machine, and all feeds can be made automatic if desired.

33. Rotary Planing Machines.

Machines in which rotating cutters take the place of reciprocating or stationary tools belong to the milling machine

division rather than to that of planing machines and will be treated in a separate chapter. There are, however, certain rotary planing and slabbing machines which occupy so directly the same field as planing machines as to demand attention in this chapter.

The first of these is the so-called rotary planer as illustrated in Fig. 22. This machine is essentially a large traverse shaper (see Fig. 18) with the reciprocating ram and tool head

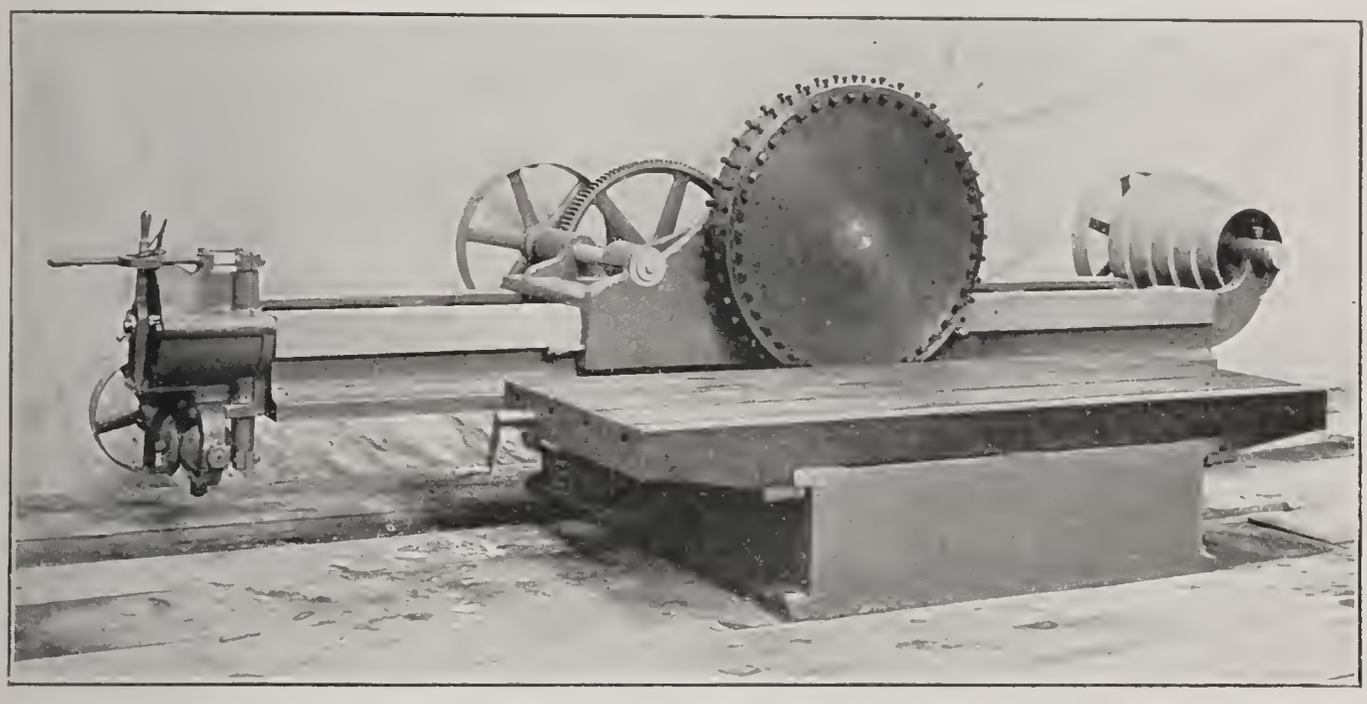

FIG. 22.

ROTARY PLANING MACHINE: HEAD 36-INCH DIAMETER.

Wm. Sellers and Co., Philadelphia, Pa.

replaced by a rotating disc of large diameter equipped with inserted cutters.

This revolving tool-head is carried on a saddle which travels on ways and is driven by a power feed. The table of the machine has a transverse adjustment for setting the work. In some cases the entire machine is mounted on a turn-table and can be rotated to any point of the compass, the driving shaft being so connected to the machine by bevel gears as to permit this. As the machines are usually constructed, only the face of the tool head is fitted with cutters, and the machine is intended for vertical surfacing alone. This planer is especially well adapted for surfacing the ends and joints of large

structural pieces such as the members of bridges, cranes, hoists, etc., and possesses a rigidity which ensures accurate work. It is extremely difficult to do such on the ordinary planer or shaper on account of the springing and wear of the tool.

Here the solitary cutting tool is replaced by forty or fifty, each one short and firmly supported.

The machine, however, possesses no adaptability and can only be regarded as a special tool.

34. Heavy Milling Machines.

There is manufactured in this country a type of milling machine which so much resembles the planing machine in its frame construction and in its various adjustments and feeds as to entitle it to be considered in this connection. This type is sometimes known as the Ingersoll Milling Machine because the Ingersoll Company of Rockford, Illinois, makes a specialty of its manufacture.

The building of these machines is not, however, confined to this one company.

Fig. 23 shows a 36-inch machine of the planer type. The resemblance to the planing machine in most of the details is noticeable. In fact the bed, the table, the housings, the top-brace are so much like those of the planer as to need but little description. The travel of the table is so slow and so slight compared with that of a planer table that some changes are necessary. The ways are now flat instead of V-shaped, and either angular or square-gibbed slides are used, like those on a shaping machine. (See Figs. 23 and 24.) The table in Fig. 23 is in some respects more like that of a milling machine in the arrangement of the slots and the surrounding pan for chips. No reciprocating motion in the strict sense is needed, but a quick return by power is provided. Instead of cutting speeds of 20 and 25 feet per minute a travel of 2 or 3 feet per minute is a maximum, and very much less than this is of course the rule.

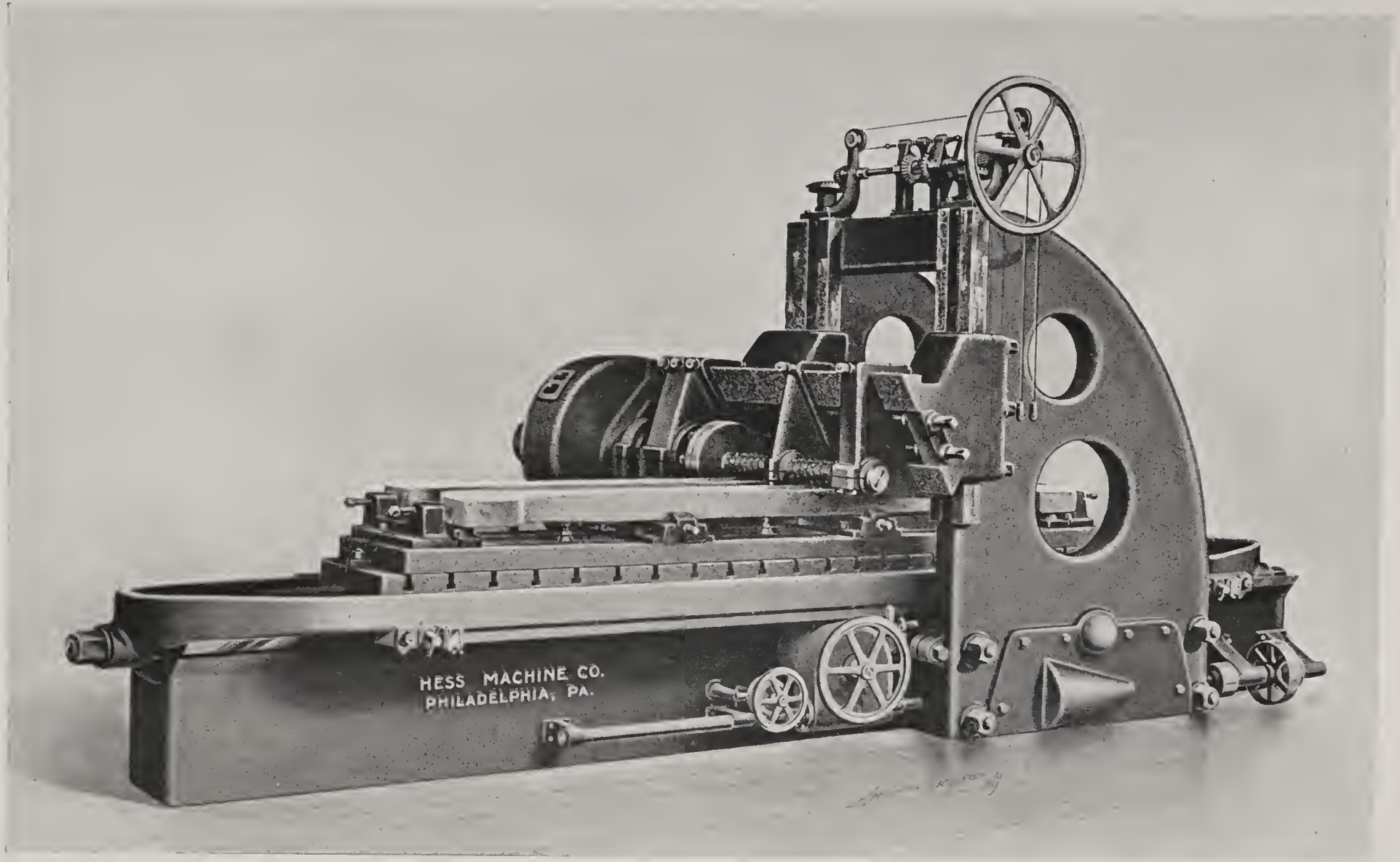

FIG. 23.

36-INCH HEAVY MILLING MACHINE.

The Hess Machine Co., Philadelphia, Pa.

The housings, the top-brace, and the ways for the cross-rail and side-heads do not differ from those of an ordinary planing machine and need no additional description.

Fig. 23 represents a machine equipped for horizontal work alone, while that shown in Fig. 24 has both top and side heads and can do any work that can be done by the standard planer.

In the former case, the face of the cross-rail is tipped to an angle of 45 degrees to bring the milling spindle in a symmetrical position with respect to the rail, and thus afford the most room for swinging the cutters.

The massive construction of the cross-rail will be noted; the necessity for this is apparent when we consider that the makers guarantee for a 42-inch machine the removal of 210 cubic inches or 54 pounds of ordinary cast-iron per minute. This means a cut 42 inches wide and $\frac{1}{2}$-inch deep at the rate of 10 inches per minute.

With the 36-inch machine shown in Fig. 23 the makers guarantee a $\frac{1}{2}$-inch cut the full width of the machine and 8 feet long in 30 minutes or 57·6 cubic inches of cast iron per minute. No planing machine could approach these figures.

To give some idea of the stresses in these machines, it may be noted that the maximum pressure at the surface of a 6-inch cutter on the 36-inch machine is given as 52,000 pounds. On the other hand, it must be remembered that the pressure is steady, and that the shocks incident to reciprocation are absent.

Fig. 24 represents a machine equipped for general work, there being two cutter-heads on the cross-rail and two side-heads. These heads have the same automatic feeds and the same adjustments as those in the ordinary type of planing machine. Each head carries a rotating spindle for the attachment of cutters, and can be used separately or in combination with its mates.

The rotary motion is imparted either by spur gears or by worms and wheels, necessitating of course considerable

complication and expense as compared with the standard planer.

The milling machine of this type can, however, do more

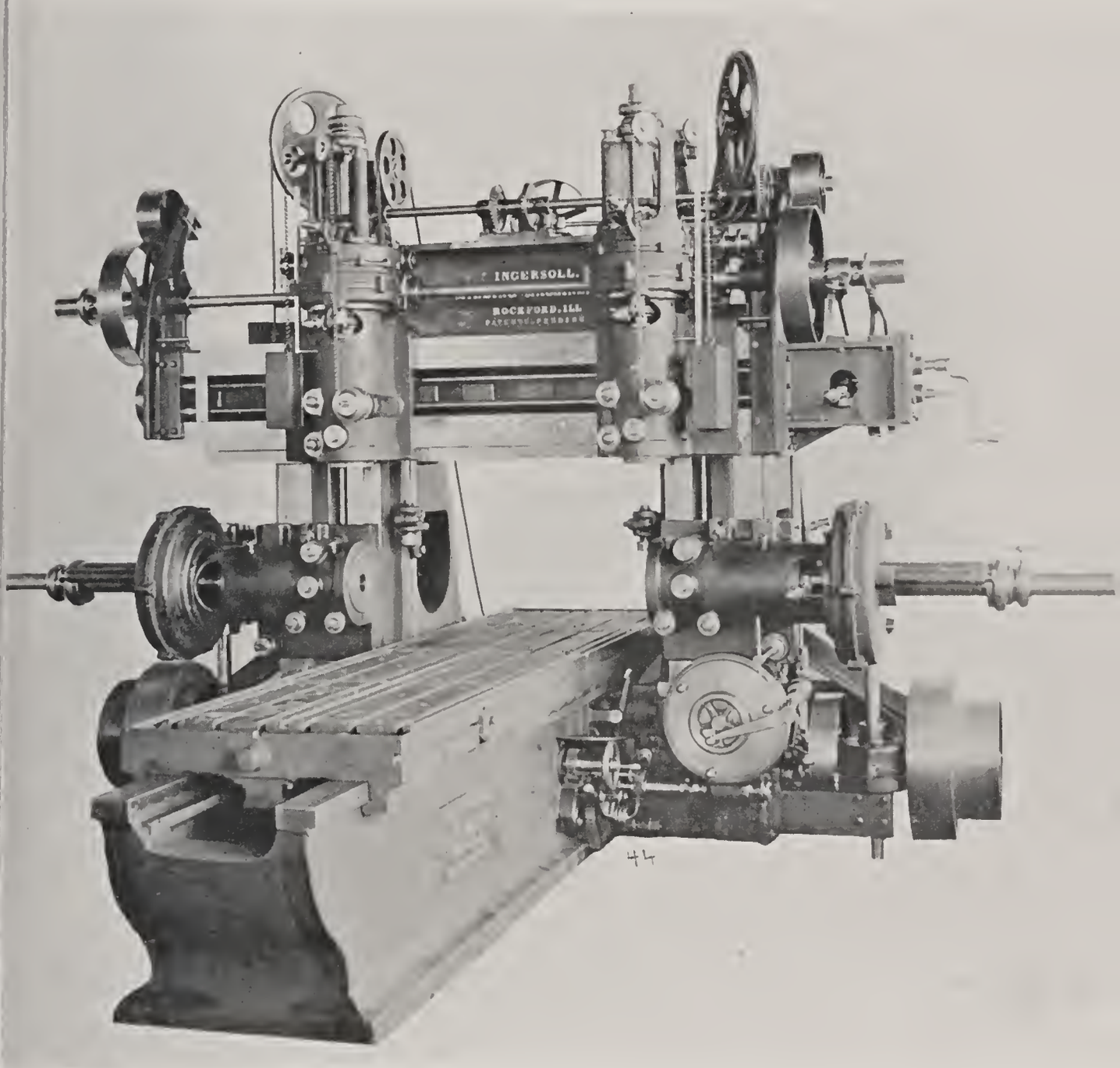

FIG. 24.

48-INCH FOUR-HEAD MILLING MACHINE.

The Ingersoll Milling Machine Co., Rockford, Ill.

work than the planing machine and can do more kinds of work, cutting into and under projections where the planer would be at fault.

Tools with inserted cutters are the rule in heavy milling.

A face mill of this description 18 or 20 inches in diameter

can remove in a roughing cut 36 cubic inches of iron per minute.

The inserted teeth can be made of ordinary tool steel or of air-hardening steel as may be desired.

There are various modifications of the heavy milling machines as there are of the planer, such as widened machines, open-side machines, etc. Machines are also made which are intended solely for vertical work or for special forms. The variety of work which can be done on a milling machine is probably greater than can be expected of any other machine in the shop.

35. Miscellaneous Machines.

This chapter and the preceding one treat of machines for producing flat surfaces, exclusive of grinding machinery, which will be treated in a chapter by itself.

Planing, shaping and milling machines with their modifications have so far been considered, and these form a large majority. The remaining machines in this class may rather be considered as special machines and not of so much general interest.

Mention might be made of plate-planing machines for straightening and bevelling the edges of plates preparatory to riveting and calking. These are in principle large traverse shapers with special attachment for holding the plates.

Also of vertical planing machines, where the housings are parallel to the table and the cross-rail stands in a vertical position. This arrangement makes the machine particularly well adapted for taking side-cuts, that is, for planing vertical instead of horizontal surfaces.

While such machines are valuable for special work they would have no place in the ordinary run of machine shops, since they are too expensive to be allowed to stand idle.

Considering in general machines for cutting straight lines on metal as they have been described and illustrated in this

and the preceding chapter, we find the main characteristics to be rigidity, speed, and convenience. Comparing machines made in the United States now with those made twenty and even ten years ago, there is evident a marked improvement in all three characteristics. The increase in strength and stiffness and in the area of bearing surfaces has made greater capacity and greater accuracy possible. The increasing use of air-hardening steels for cutting tools has brought about greater cutting speeds, although this is not so marked in planing machines as it is in lathes.

But it is in adaptability, in capacity for a wide range of work, and in convenience of operation, that the modern machine leads all its predecessors. This is what increases the output of a machine more than mere strength or speed.

'Slaughtering stock' by taking deep and wide cuts is sometimes necessary, but as a rule it only evidences poor management. The normal function of a machine tool is not to remove the most metal possible in a given time, but to finish the work in the least time with the greatest accuracy and with the least waste of material. It is this feature of the machines just described which is most to their credit and which has so enormously increased the output per man and per machine in the last decade.

The use of two or more cutting tools at a time, the automatic power feeds in all directions, and the arrangement of adjusting cranks and controlling levers within easy reach of the operator, have all helped in this development.

CHAPTER III

ENGINE LATHES

36. Lathes in General.

As lathes are used in the ordinary machine shop they may be classified as follows: (1) hand lathes or those used for hand finishing and polishing; (2) engine lathes either with or without screw-cutting attachments; (3) turret lathes equipped with a turret in place of a carriage and tailstock; (4) special lathes such as are used on only one class of work. As the so-called engine lathe is the most general in its capacity for doing all varieties of work and is the most used of any of those above mentioned, it will be first considered.

The elements of which a lathe is constituted may be thus briefly indicated: (*a*) the bed; (*b*) the headstock and its spindle; (*c*) the carriage and its mechanism; (*d*) the tail or footstock for supporting one end of the work; (*e*) the gearing for changes of speed; (*f*) the feed mechanism; (*g*) the mechanism for cutting threads.

37. The Bed.

The strains which come on the lathe bed are twofold: first, the bending due to the weight of the carriage and the pressure on the tool; and second, the twisting due to the pressure on the tool when turning large work and to the uneven support of the legs. As usually designed, the bed is well adapted to resist the bending but has very little capacity to withstand torsion. It consists of two parallel girders approximately of an I-section connected at intervals by cross-

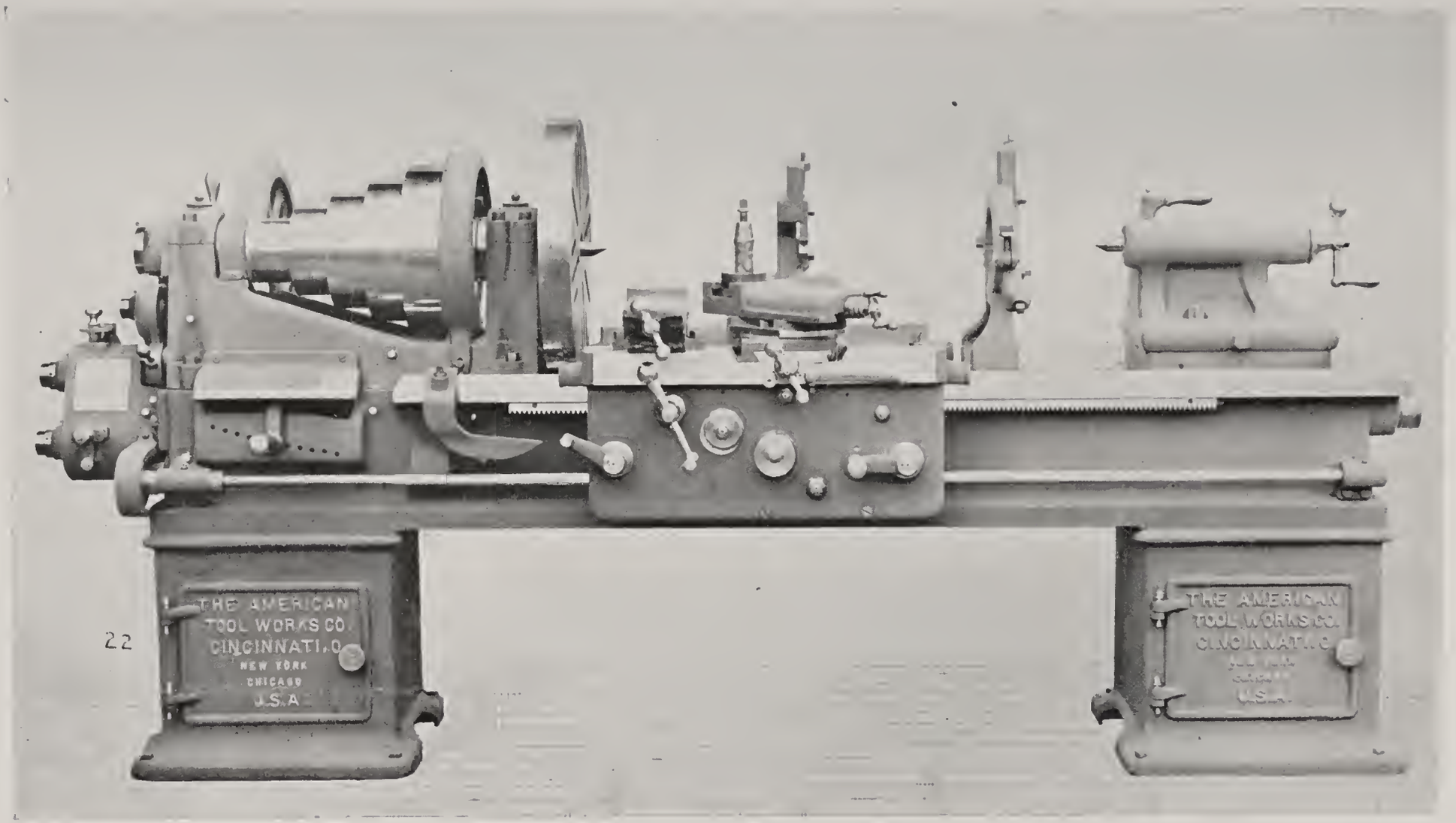

FIG. 25.

20-INCH AMERICAN LATHE.

The American Tool Works Co., Cincinnati, Ohio.

girts and supported on legs. This form in its various modifications has come about rather as an adaptation of the frame to the moving parts than as an attempt to meet the conditions of strength and stiffness. The tops of the girders are convenient for attaching the fixed and moving parts, the recesses in the sides for locating the feed rods and lead screws, and the bottoms for fastening to the supports. The ideal cross-section, as far as strength is concerned, is the box form having its depth considerably greater than its breadth and the metal reinforced at top and bottom. In other words, complete the present form by covering the gap at top and bottom. Some enterprising builder will yet do this and make a bed having four times the stiffness for the same weight. The legs of the modern lathe are usually homely, and it would seem unnecessarily so. The use of reverse curves without apparent reason and the ungainly spreading of the leg in every direction give it an absurd appearance.

As the beds increase in size and weight, cabinets or columns are substituted for the legs at one or both ends, as shown in Figs. 25 and 26. The combination of cabinet at one end and leg at the other is not pleasing and must be considered poor design. The convenience of cabinets as receptacles for gears, wrenches, and other adjuncts of the lathe is too apparent to need discussion. As the weight increases the cabinets naturally become more stocky, as in Figs. 27 and 28, and finally disappear altogether, the bed reaching to the floor and resting on stone, brick, or concrete foundations. (See Fig. 29.)

Uneven support by the legs is one serious cause of twisting in the beds of small and medium-sized lathes. This can be easily obviated by supporting the right end of the lathe on a hinge or rocker with its axis parallel to the lathe bed, thus allowing the leg to adjust itself for any lack of alignment in floor or foundations.

The ways of American lathes are almost universally of the inverted V type, the angle between the sides of the V being about 90 degrees. The two outer ways are used for guiding the carriage and the inner ones for the tailstock. Flat ways

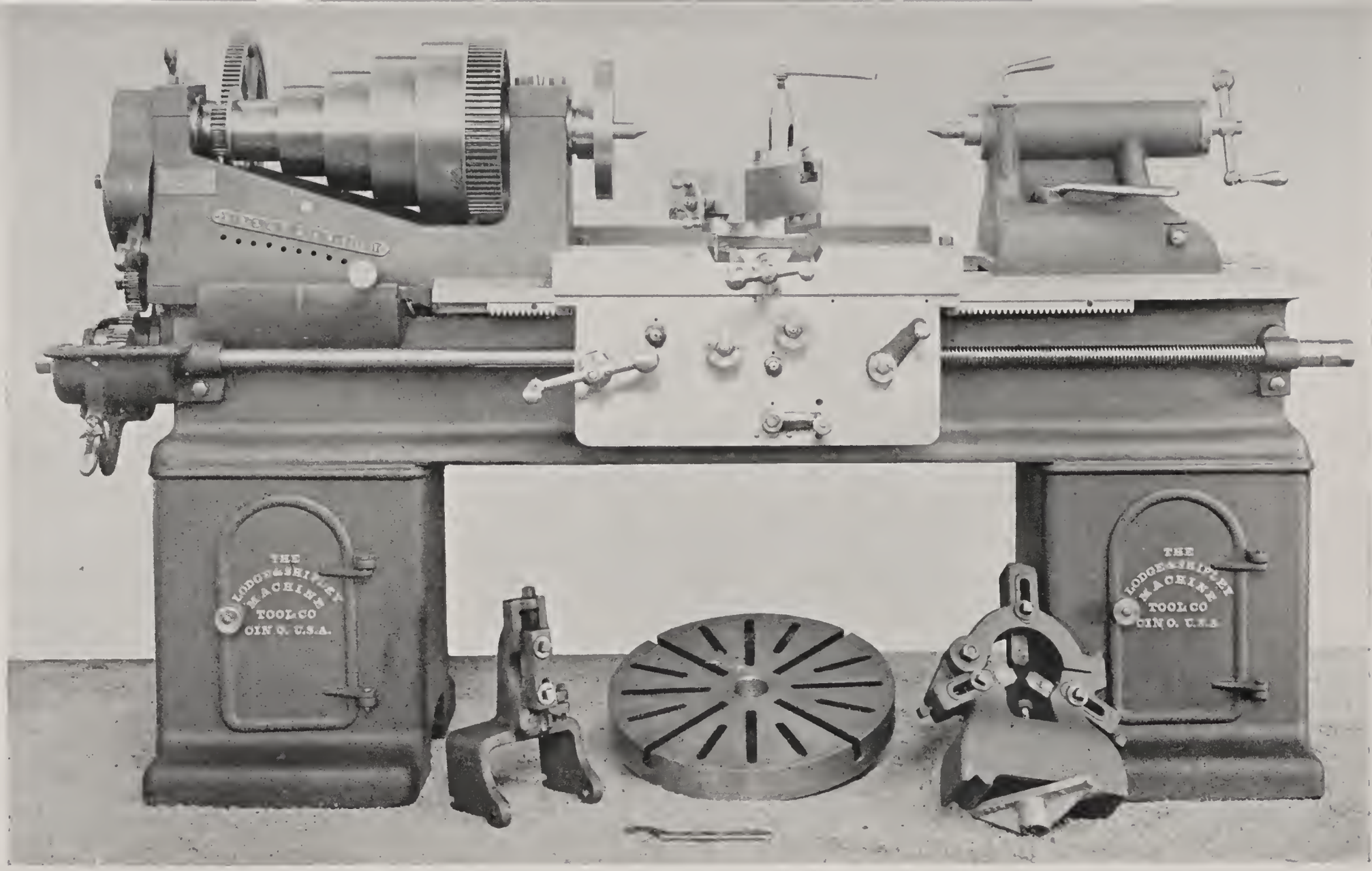

FIG. 26.

20-INCH × 6-FEET ENGINE LATHE.

Lodge and Shipley Machine Tool Co., Cincinnati, Ohio.

have found little favour in the United States, one reason being the difficulty of keeping them clear of chips. On some lathes the inner ways are depressed as shown in Fig. 37, thus affording more room for bracing the carriage and giving more swing to the lathe.

In others the inner V's are omitted altogether, and the tailstock is guided on flat ways with bevelled edges. The omission of one V and reliance on the other for guidance is also a common modification.

The principal change of late years in the ways of engine lathes has been towards an increase of bearing area and of the angle between the two sides of the V.

As regards the general design of bed and legs, it may be said that there is of late a marked improvement in the way of simplicity, absence of ornament, and increase of strength. There still remains, however, the possibility of improvement by reverting to the closed box section, if the moving parts can be successfully adapted to this form.

The use of pan frame for catching oil and chips has usually been confined to turret lathes, but several makers are supplying them when desired with their standard engine lathes. (See Fig. 32.)

38. The Headstock.

This is of practically the same pattern in all American lathes, as may be seen by reference to the various illustrations. It consists of a ribbed arch spanning the gap between the ways, sloped to match the shape of the cone pulley and having box-shaped standards at either end for the reception of the spindle boxes. In the best design the arch is continuous, and is not cut away under the cone. Even the reversing gear is sometimes moved outside to avoid weakening the headstock by cutting into it. In heavy turning on large work the principal strain on the headstock is a direct lift on the main spindle box; but in addition to this there is always more or less horizontal pressure tending to spring the box sideways. A comparison of the lathes shown in the illustra-

tions with those made ten years ago will show a decided increase in the length and diameter of spindle bearings and in

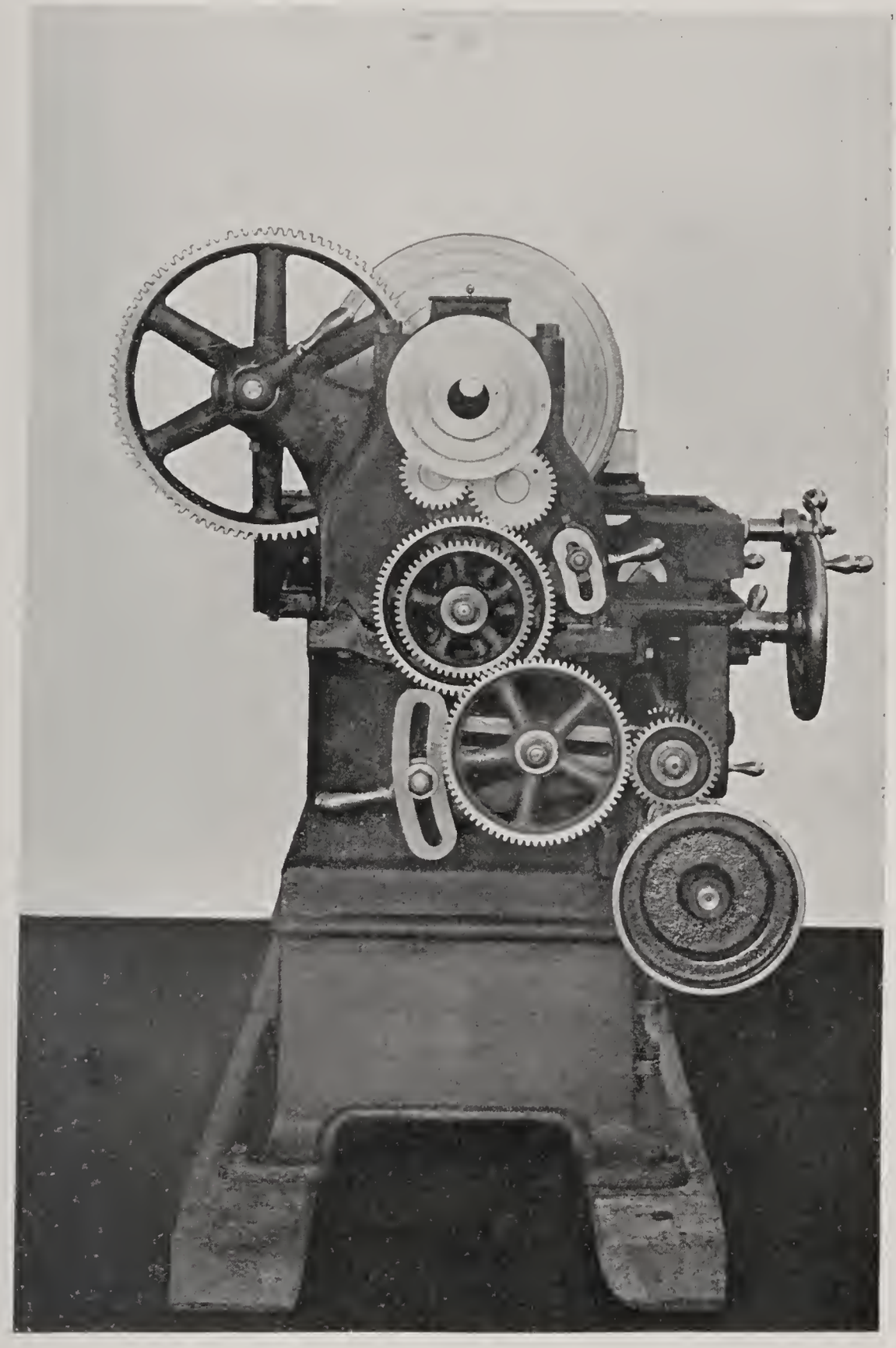

FIG. 27.

24-INCH LATHE—END VIEW.

The R. K. Le Blond Tool Co., Cincinnati, Ohio.

the width of steps on the cone. Fig. 30 shows the shape of the headstock and the general arrangement of the moving

parts in one such lathe. The only break in the continuity of the headstock is the one small opening for drainage.

39. The Spindle.

The main features of the head combination are the spindle and its boxes, the cone and back gears, and finally the feed-gearing connections. As is shown in Figs. 30 and 31 the spindle is usually hollow, allowing small rods to be finished in a chuck and then cut off. In fact the advantages of a hollow spindle are too apparent to need discussion. The one shown in Fig. 31 has an unusually large bore when the bushing and centre are removed. The journals are long and of large diameter, especially the one next the face plate. This latter journal may be considered one of the critical points in any lathe. Upon its accuracy and its stiffness depend the quality of all work done on the machine. Its length determines the coolness of running at high speeds, its projected area must be sufficient to prevent squeezing out of the oil under heavy pressures, while its diameter must ensure strength and rigidity against torsion and bending.

Crucible steel is the metal generally used, as this metal is strong and wears well. The bearings are usually ground, and the collars which take the end thrust are hardened and ground. The spindle boxes are made of phosphor bronze or other composition metal which can be readily cast, which presents a good rubbing surface when finished, and which will hold the oil. In many modern lathes lubrication is effected by ring oilers, as may be seen in Figs. 30 and 31. These illustrations also show two different types of box. That illustrated in Fig. 31 is the more common, a cylindrical bearing with the box parting in a horizontal plane through the centre. The cap is fastened by screws, and adjustment is effected by lining up or by planing.

With bearings of the proportions shown and with continuous oiling the wear should be very slight and adjustment seldom needed.

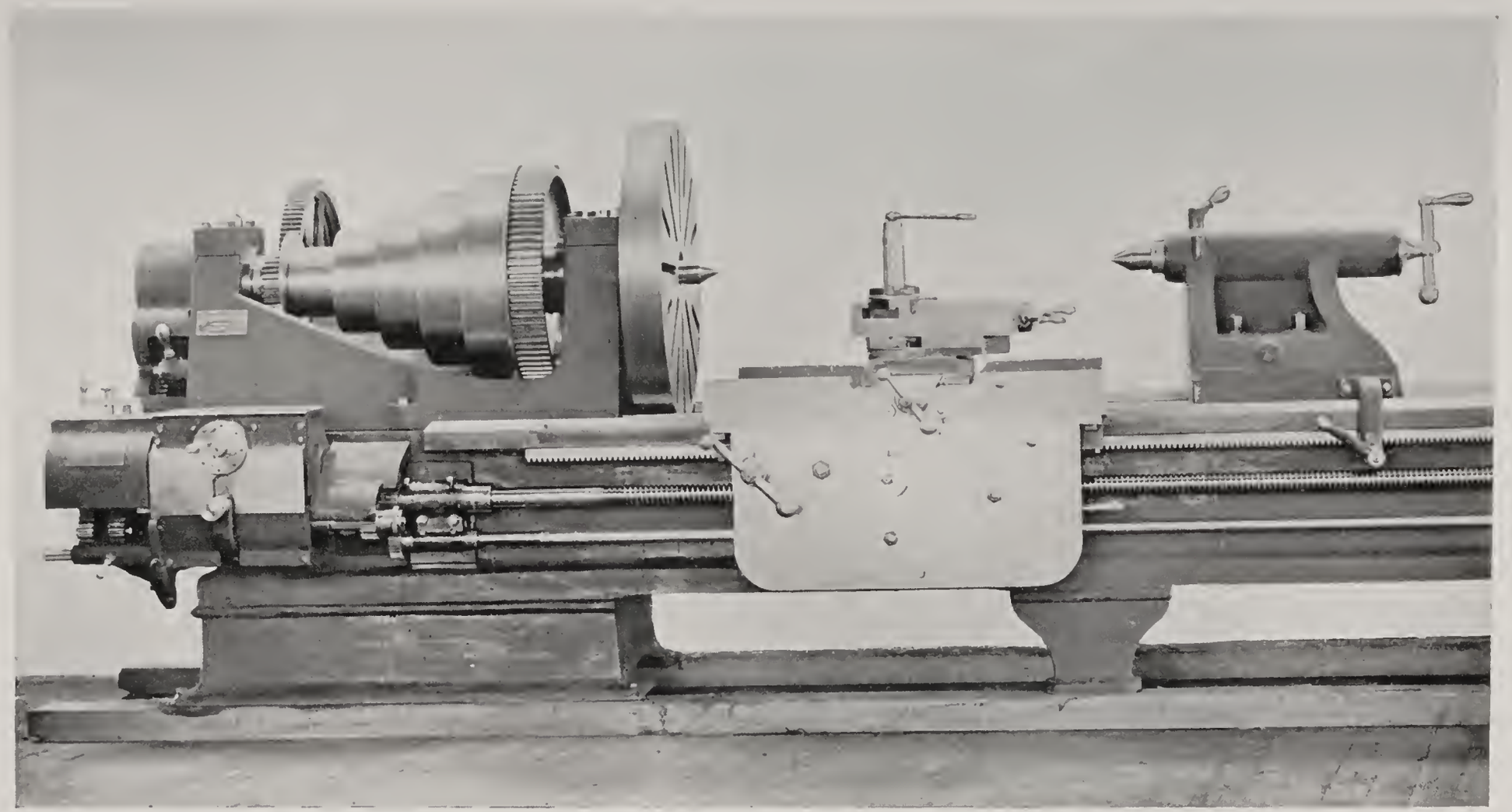

FIG. 28.

30-INCH ENGINE LATHE.

Schumacher and Boye, Cincinnati, Ohio.

The lathe illustrated in Fig. 32 has cylindrical journals on the spindle, but the boxes are conical on the outside and are adjusted by means of rings screwed on the ends forcing them in or out of conical seats in the headstock, thus keeping the spindle always in line.

The lathe illustrated in Fig. 30, on the other hand, has conical bearings for its spindle, and adjustment is effected by endwise movement of spindle.

The proportions of the cone and thrust collar at the front end are so adjusted that they shall wear together. The box at the rear has a separate adjustment. The arrangement just described permits of having a solid box and always keeps the alignment of the spindle perfect.

The makers state that they have in their own shops bearings of this description which have been in constant use for two years without readjustment.

A comparison of the spindle and cone dimensions for several of the lathes shown by the illustrations gives the following as average measurements :—

TABLE IV

Swing.	Front Bearing.		Cone Steps.		
Inches.	Diam.	Length.	Width.	Diameter.	
				Large.	Small.
14	2·25	4·25	2·25	9·0	3·5
16	2·75	4·875	2·625	10·5	4·0
18	3·0	5·0	2·625	12·5	4·5
20	3·25	5·5	3·125	13·0	4·75
24	4·0	7·0	3·625	15·5	6·0
30	5·0	8·0	4·25	20·0	7·0
36	6·0	9·0	4·75	22·0	8·5
42	6·0	10·0	usually triple instead of double geared.		
48	7·0	12·0			

Of course this table does not give a logical system of dimensions, but merely represents the average of the measurements for each size of lathe.

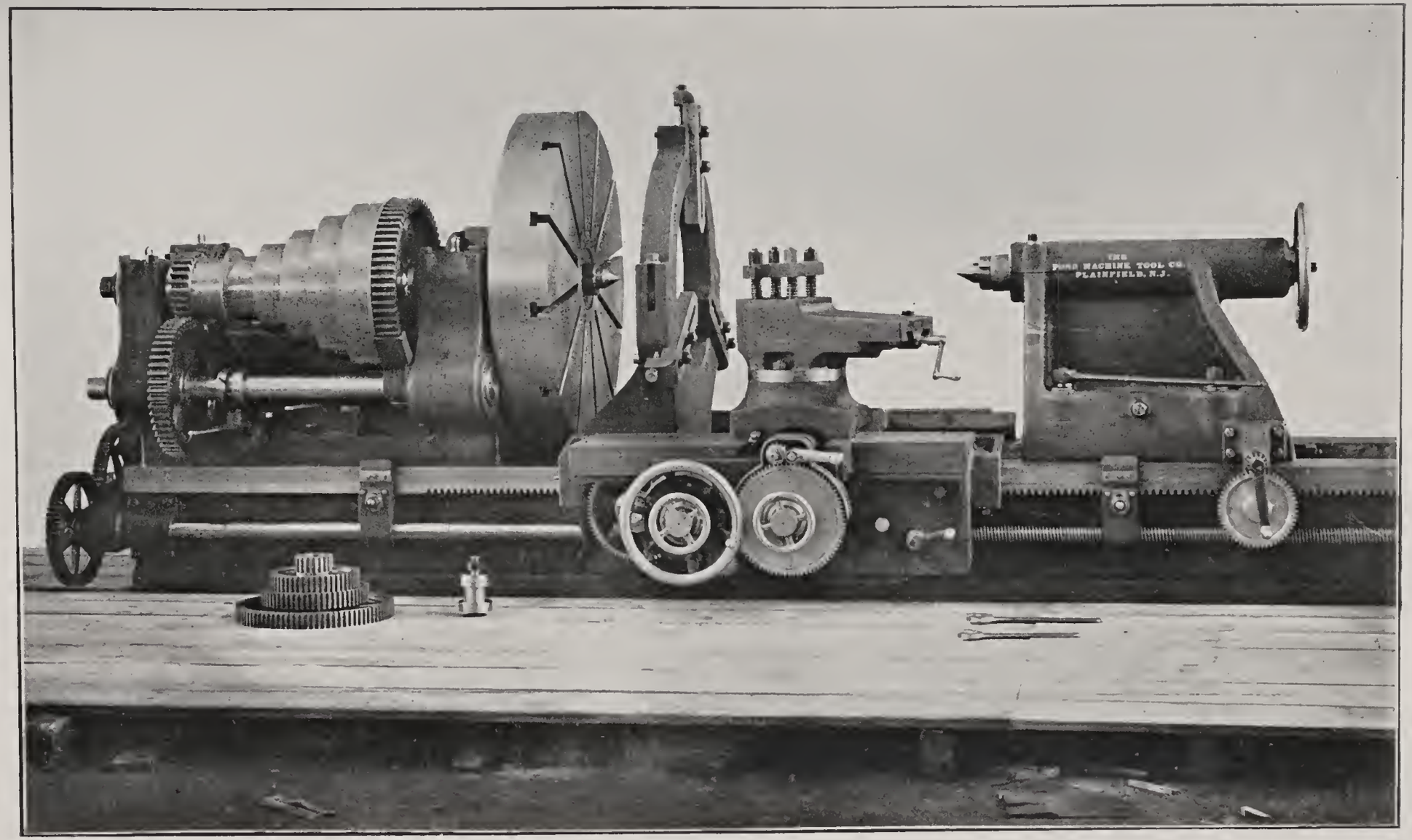

FIG. 29.

54-INCH POND ENGINE LATHE.

Niles-Bement-Pond Co., New York.

40. Speed Gearing.

Lathes of the standard type are equipped with cone pulleys and back or double gearing to give the necessary changes in speed. The cone pulley and the small gear at the left (Fig. 30) forming one part and running loose on the spindle, transmits motion to the latter through the back gears and the large front gear on the spindle. When high speeds are desired, the back gearing is thrown out and the cone clamped directly

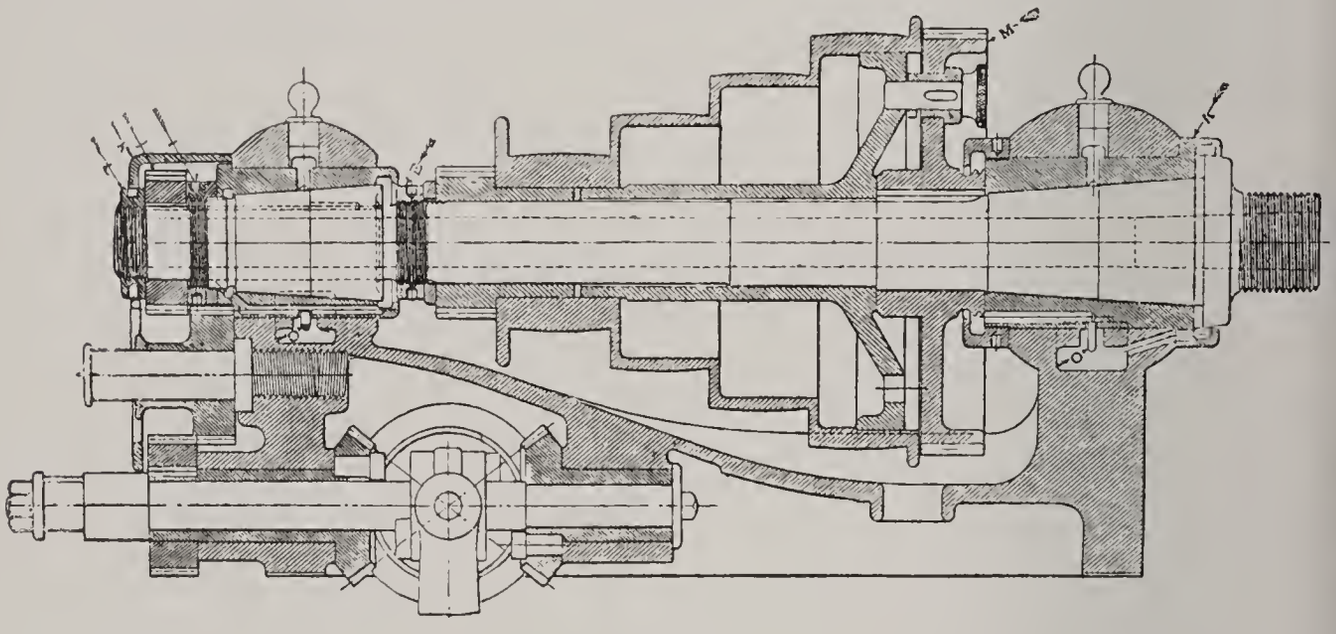

FIG. 30.

IMPROVED HEADSTOCK OF ENGINE LATHE.

The Hendey Machine Co.

to the front gear by a screw or some other means. This time-honoured device is probably a survival of the fittest and will continue to be used indefinitely.

The protection of the spindle gears by shields is a feature that will be appreciated by most users of lathes. (See Fig. 25.) The matter of proper lubrication between cone and spindle deserves more attention than has apparently been given to it. When the back gears are in use the cone is in the condition of a loose pulley, and the tendency of the oil is to fly out away from the spindle. The usual method of oiling by tubes from the outside of cone is a very poor solution and the sticking of the cone on the spindle an annoying accident.

Another disagreeable feature of some lathes is the ten-

dency of the back gears to fly out when in use. This is overcome to a greater or less extent in modern lathes by having the eccentric which controls the gears slip by the centre far enough to lock against the working pressure. One such

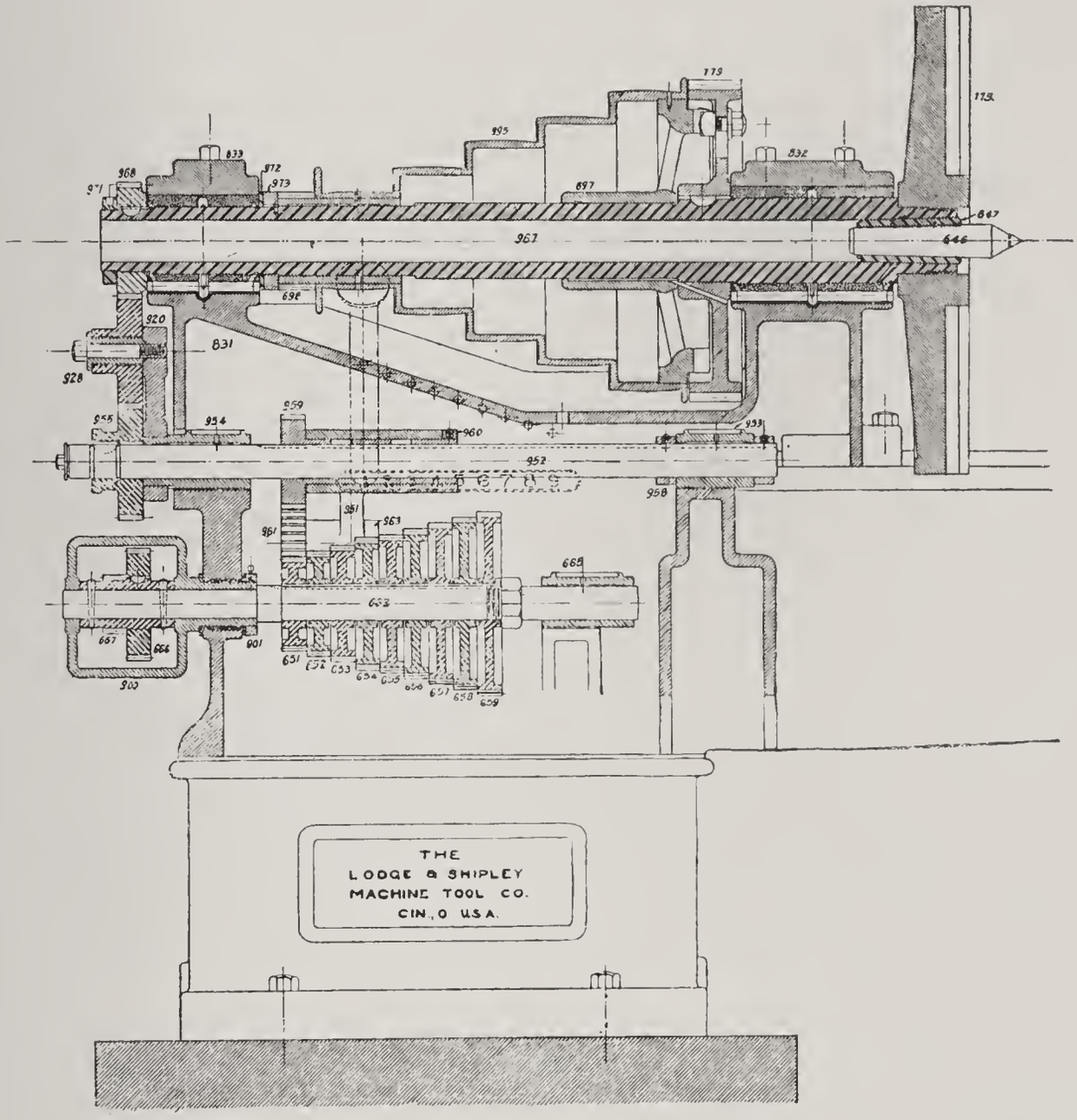

FIG. 31.

HEADSTOCK OF LATHE.

Lodge and Shipley Machine Tool Co., Cincinnati, Ohio.

lathe is equipped with friction gearing in the headstock, which can be changed while the spindle is in motion by means of a lever in front of the headstock. This arrangement is particularly convenient when finishing small parts requiring frequent changes of speed. The time lost in changing back gears in the ordinary way would be considerable in

such case. The number of steps on the cone is either four or five, and the steps are generally of uniform height. This arrangement gives approximately a regular geometrical progression of speeds, and the back gearing is so graduated as to preserve this ratio. That is to say, it ought to be; candour compels the admission that it is not always so graduated.

An examination of several of the lathes illustrated in this chapter shows a gearing ratio of about 10 to 1 as the average for 16-inch lathes, and a geometrical ratio of speed change from one step to the next of about 1·5. To illustrate this the following figures are quoted from one of the catalogues :—

Swing over bed, $16\frac{1}{4}$ inches.
Ratio of back gearing, 9·25 to 1.
Head-cone diameters, $3\frac{3}{4}$, $5\frac{7}{16}$, $7\frac{1}{8}$, $8\frac{13}{16}$, $10\frac{1}{2}$ inches.
Countershaft cone diameters, $12\frac{1}{2}$, $10\frac{13}{16}$, $9\frac{1}{8}$, $7\frac{7}{16}$, $5\frac{3}{4}$.
Speed of countershaft, 100 revolutions per minute.

The speeds of the lathe spindle will accordingly be as follows :—

Without Gear.					With Gear.				
333	199	128	84·5	54·75	35	21·5	13·8	9·15	5·92

The successive values of the speed-change ratio from step to step are :—

1·67 1·55 1·52 1·54 1·52 1·67 1·55 1·52 1·54

The slowest speed, or 5·92 revolutions per minute, would give a cutting speed of about 25 feet per minute at the periphery of a circle 16 inches in diameter.

Double back-gears are used where it is necessary to get a greater range of speeds without increasing the number of steps on the cone. The Draper lathe has two sets of gears at the back end of the spindle so arranged that either set may be thrown into mesh at will. With this arrangement it is usual to have less difference between the diameter of the successive steps than in the single-geared headstock. The lathe is more powerful with the belt on the small step than the ordinary lathe, and the belt is more readily shifted from

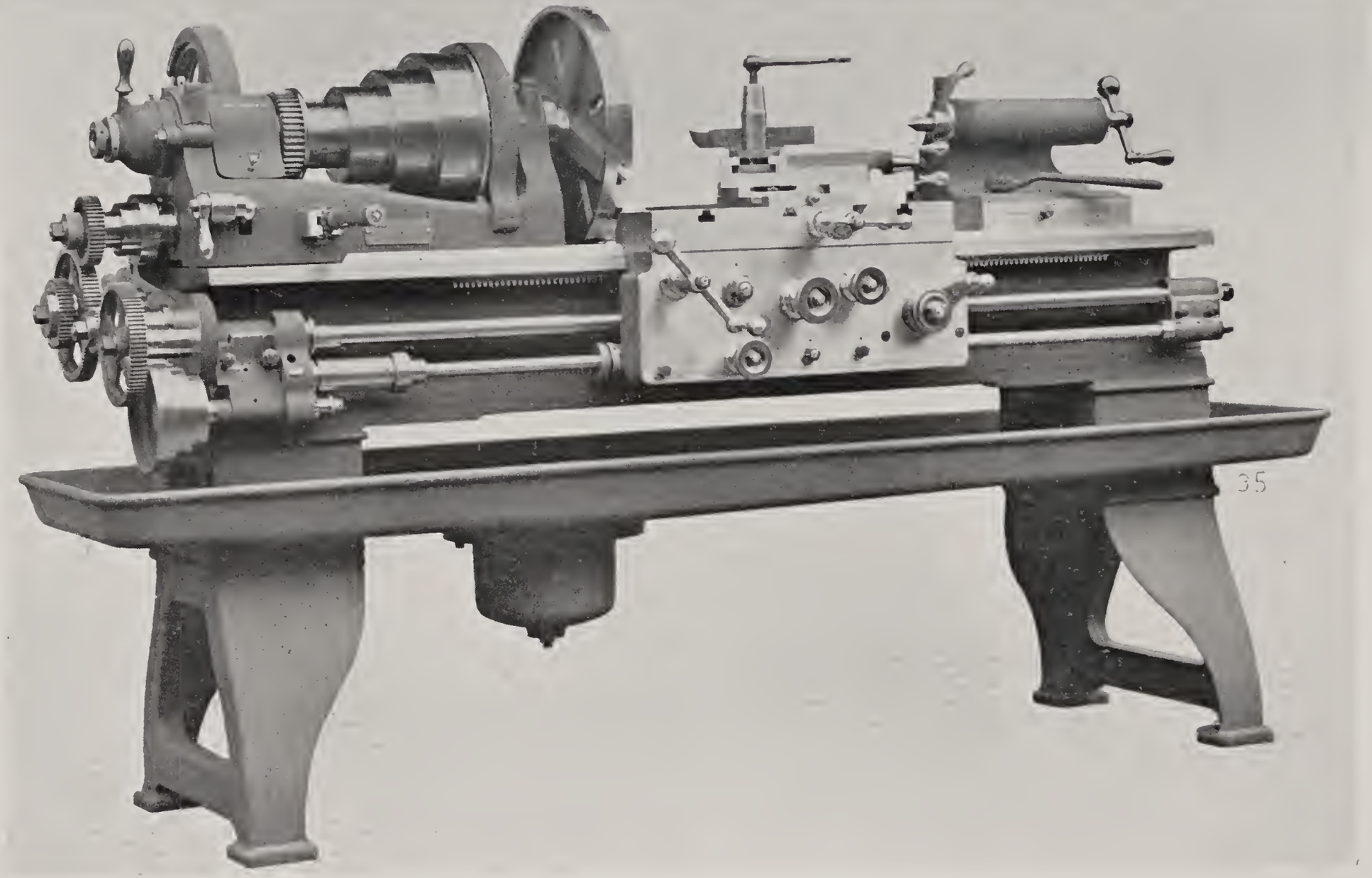

FIG. 32.

16-INCH LATHE, WITH PAN.

The Bradford Machine Tool Co., Cincinnati, Ohio.

one step to another. The following figures give a reasonable arrangement for a double back-geared 24-inch lathe :—

Ratio of first back-gearing, 4·3 to 1.
Ratio of second back-gearing, 18·5 to 1.
Head-cone diameters, 16, $13\frac{3}{4}$, $11\frac{1}{2}$, $9\frac{1}{4}$.
Speed of countershaft, 80 revolutions per minute.

Assuming the cone on the countershaft to be the same as the head cone we have the following range of speeds :—

Without Gear.				First Gear.				Second Gear.			
138	95·5	67	46	32	22	15·5	10·7	7·5	5·15	3·6	2·5

The ratio is practically uniform and is 1·45. The slowest speed, or $2\frac{1}{2}$ revolutions per minute, would give a cutting speed of about 16 feet per minute on a 24-inch circle.

Lathes of over 30-inches swing are usually triple-geared, as is illustrated in Fig. 29. A triple-geared headstock is one in which there are two back-gear spindles, the slower one usually gearing directly with the face plate or chuck. This arrangement is most clearly shown in Fig. 33. For convenience and for greater driving power the gearing is usually placed on the front side of the head. This brings the pinion which drives the face plate nearly in line with the cutting tool. As will be seen from the illustration, the gearing is so arranged that the spindle may be driven directly by the cone, indirectly by the upper set of gears, or indirectly through both sets of gears and the face plate. As there are five steps on the cone, this device gives fifteen changes of speed. When handling heavy work on the face plate, the gearing direct to teeth on the latter near the cutting tool removes the tendency to springing and chattering.

The arrangement of cone steps and gears on a 42-inch lathe is in one instance as follows :—

Ratio of back gearing, $6\frac{1}{4}$ to 1.
Ratio of triple gearing, $40\frac{5}{8}$ to 1.
Head-cone diameters, $10\frac{1}{2}$, $13\frac{3}{8}$, $16\frac{1}{4}$, $19\frac{1}{8}$, 22 inches.
Countershaft ,, 22, $19\frac{1}{8}$, $16\frac{1}{4}$, $13\frac{3}{8}$, $10\frac{1}{2}$ inches.
Speed of countershaft, 100 revolutions per minute.

The corresponding speeds of spindle will be as follows :—

Direct.	Double Gear.	Triple Gear.
210, 143, 100, 70, 47·7	33·6, 22·9, 16, 11·2, 7·6	5·17, 3·52, 2·46, 1·72, 1·17

The geometrical ratios from one speed to the next are as follows :—

1·47 1·43 1·43 1·47 1·42 1·47 1·43 1·43 1·47 etc. etc.,

an average of 1·45 as in the previous example. Calculating the cutting as heretofore for the slowest speed of the lathe,

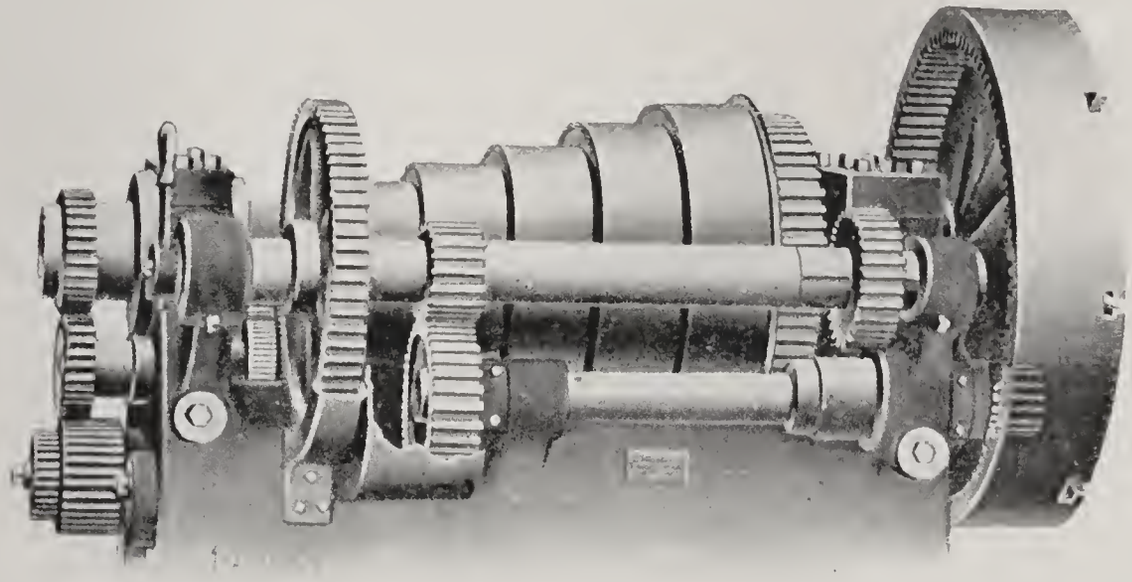

Fig. 33.

LATHE HEAD, WITH TRIPLE GEAR.

The Bradford Machine Tool Co., Cincinnati, Ohio.

we find it to be about 13 feet per minute at the circumference of a circle 42 inches in diameter.

41. Feed Control.

For feeding the carriages along the ways some lathes have a lead screw working in a split nut on the apron, some a splined screw driving gears in the apron which engage with a rack on the bed, and some a splined feed-rod entirely distinct from the lead screw.

Although the lead screw is the universal means of driving the carriage for thread cutting, it is not well adapted for

ordinary turning. Being a positive gear, it is inconvenient to throw in or out when starting and stopping a cut. Add to this the fact that the continual wear inseparable from its use for ordinary turning would soon ruin it for screw cutting, and there are reasons enough for the adoption of a separate device for feeding the carriage. Cutting a spline on the lead screw that it may operate gears on the carriage is a compromise which has little to recommend it, as the spline forms cutting edges on the threads of the screw and these wear the nut rapidly. Large lathes which are to be used almost exclusively for ordinary turning may be made without a separate feed-rod, but for the small everyday lathe it is almost indispensable.

An inspection of the illustrations in this chapter will show that nearly all the American lathes have the lead screw for thread cutting and the combination of splined feed-rod and stationary rack for turning. The mechanism for actuating the feed-rod and lead screw is practically the same in most lathes, and consists of a train of gears driven by a pinion on the rear end of the spindle either inside or outside of head. The gear for reversing the direction of feed usually consists of two pinions on a swinging sector, either one of which may be brought in mesh with the spindle pinion by means of a convenient lever. This is the case with the lathes shown in Figs. 26 and 27. Fig. 27 gives an end view of a lathe geared on this principle, and shows the connection between spindle and lead screw so clearly as to need no explanation. In Fig. 30 the reversing mechanism is seen to be underneath the headstock and to consist of two bevel pinions revolving in opposite directions, either one of which may be engaged with a clutch on the shaft which drives the feed.

This clutch is operated by a reversing rod running the whole length of the bed and manipulated at the carriage, and is also controlled by an automatic stop-rod worked by the carriage.

This last-described method has the advantage of not

requiring the meshing of gears, and therefore can be readily operated when the lathe is running.

From the nature of its use the lead screw is necessarily driven by gearing without the use of belts or other friction devices. It is usually disconnected from the carriage or apron by a split nut (see Fig. 34) operated by a lever. When driven by a reversing motion operated from the

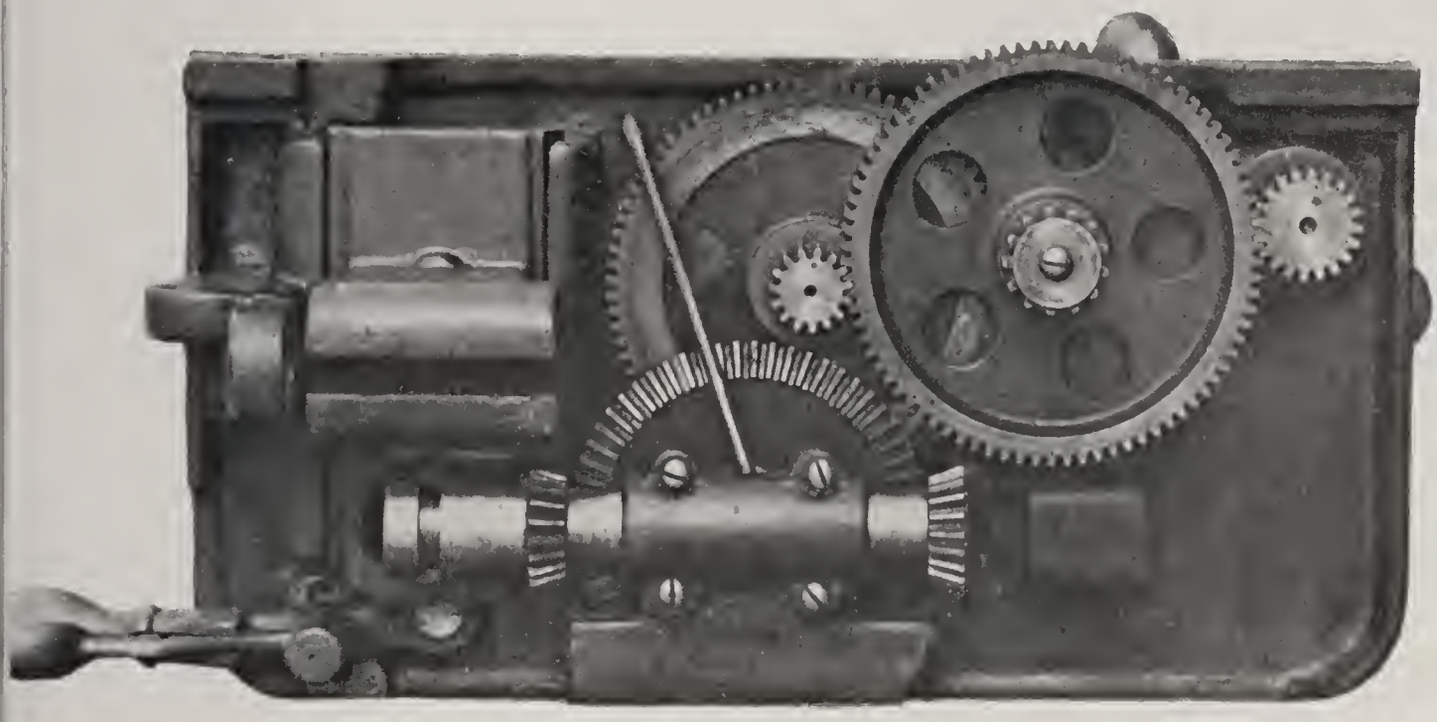

Fig. 34.

STANDARD LATHE APRON.

The R. K. Le Blond Machine Tool Co., Cincinnati, Ohio.

carriage, the lead screw may be reversed without reversing the spindle and the tool run back for another cut.

This renders reversal of the countershaft unnecessary, and makes possible a two-speed counter with two open belts, thus doubling the number of lathe speeds. The number of different threads which can be cut depends on the size of lathe, but generally includes the ordinary pitches of bolt threads and pipe threads from 1 or 2 to 32 threads per inch. The lead screw is sometimes located just inside the bed.

The feeding mechanism for plain turning may be driven by belts, by gears, or by the two combined. Fig. 27 shows the very simple method of driving the feed-rod direct from the spindle by means of a belt running on cone pulleys. For the

ordinary run of work, the simplicity and directness of this form of drive appeals to most operators. The absence of gears and of intermediate shafts with their accompanying noise and dry bearings is a welcome feature. The length of the feed belt will make it drive better and last longer. On large lathes a silent chain replaces the belt. The direct feed can be replaced by a geared feed whenever desired, and all feeds can be reversed at the carriage.

The idea of obtaining changes of feed either for turning or cutting threads without changing gears now finds considerable favour among lathe manufacturers. A series of gears is arranged in a 'nest' or group so that by merely manipulating a lever any one of the series may be brought into action. By having two sets of changes quite a number of combinations may be made. Figs. 25, 26, 28, and 31 show various modifications of this plan.

The Springfield lathe has a circular disc at the end of the head carrying eight gears arranged in a circle so that any one may be brought into line with the lead screw at will. The intermediate gears between head spindle and lead screw are arranged in pairs, such as to give five different ratios. The combination of these with the eight gears before mentioned gives forty different speeds to the lead screw. The range of threads is from 2 to 56 per inch, and the feed, being geared to the screw as 1 to 4, ranges from 8 to 224 cuts per inch.

The more usual arrangement is that shown in Fig. 31, where a nest of gears is contained in the bed under the headstock. By means of a lever in front of the head (see Fig. 26) a gear driven by the spindle may be thrown into mesh with any one of these. A series of four gears on the outside end of the cone-gear shaft multiplies the number of changes fourfold. Thus with nine gears in the cone, as shown in the cut, there would be 36 different speeds for the lead screw. The lathe shown in Fig. 26 has a range of 37 different threads from 2 to 32 per inch, any one of which may be cut without

changing any gears by simply shifting the two knobs shown in the figure.

The lathe whose headstock is shown in Fig. 30 has a somewhat similar arrangement of gears. All the regular threads from 6 to 20 are cut by the simple change of a lever, and by two further changes of intermediate gears all the regular threads from $1\frac{1}{2}$ to 80 per inch may be cut.

For ordinary changes of feed the lever alone will suffice, the ratio of feed to lead screw being 1 to 5 on an 18-inch lathe.

The 30-inch lathe illustrated in Fig. 28 has 32 changes for feeding and screw cutting without removing any gears. These changes are effected by combinations of two groups of gears, one containing four gears and the other eight. The following index is a good illustration of those used for screw cutting on this class of machines, being that for a 24-inch lathe of the same make.

INDEX

Front Index Handle in Hole,	.	.	.	1	2	3	4	5	6	7	8		
Top Index Handle in Hole, 1	Cuts	Threads per inch,	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{7}{16}$	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{3}{4}$			
,,	,,	,,	2	,,	,,	2	$2\frac{1}{4}$	$2\frac{1}{2}$	$2\frac{3}{4}$	$2\frac{7}{8}$	3	$3\frac{1}{4}$	$3\frac{1}{2}$
,,	,,	,,	3	,,	,,	4	$4\frac{1}{2}$	5	$5\frac{1}{2}$	$5\frac{3}{4}$	6	$6\frac{1}{2}$	7
,,	,,	,,	4	,,	,,	8	9	10	11	$11\frac{1}{2}$	12	13	14
,,	,,	,,	5	,,	,,	16	18	20	22	23	24	26	28
FEEDS 5 TIMES THREADS PER INCH.				W. T. Emmes Patent, Aug. 26, 1902; Oct. 28, 1902.									

It will be noticed that the feed ratio on this lathe is as 1 to 5.

Lathes having both the lock-nut screw feed and the rod feed should be so constructed that it is impossible to throw both into gear at once, as this latter combination is a most fruitful source of broken gears and racks. In some lathes it is possible to throw out the pinion from contact with the rack when cutting threads.

Summing up, it may be said that the most noticeable improvement in feed mechanism of late years is the substitution

of combination gears for the ordinary change gears, making it possible to secure almost any cut or thread by the mere shifting of a lever. The convenience of this operation as compared with the old method ensures a more frequent use of the best feed and a consequent increase of output. There has lately been a more careful study of the subject of cutting speeds and feeds, and, as has been shown, an adaptation of the lathe gearing to meet the requirements of the operator.

Another improvement is the location of the feed reverse in the apron of the carriage, a notable time-saver.

The automatic stop on most lathes makes it safe to leave the lathe running when turning long work or when doing a large number of duplicate pieces.

42. The Carriage.

There is practically but one type of lathe carriage in use on American lathes. It is of H-form in plan, with a long slide on the front way, another sliding on the rear way, and a bridge spanning the gap in the bed. The tool slide traverses the bridge from front to rear, and the whole carriage is moved by gearing attached to the apron which hangs down in front of the bed.

Although this general type is adhered to there is an almost infinite variety of detail. Fig. 35 gives a good idea of the proportions and arrangement of the ordinary carriage for a medium-sized lathe. As may be seen from the illustration, the V's are at the extreme front and rear of the bed, while the bridge is cut away to clear the head- and tail-stock ways. This weakens the bridge, and has led some makers to adopt the sunken V. The bridge is, however, reinforced at the centre by braces to resist the thrust of the tool-post when that member is located as shown in the figure. To prevent lifting or springing of the slides they are gibbed to projecting ledges on the bed as may be seen from the cut.

Some lathes of small size have a slide for the tool-post which is hinged to the front of the carriage and raised or lowered by a screw at the back. In the majority of cases, however, a compound rest is used which moves on a dove-tailed slide and is controlled by the cross-feed screw, the elevation of the tool being effected in the tool-post itself. T-slots should be milled in the top surfaces of the carriage for the attachment of work or of compound rests. (See Fig. 32.) Most lathes are fitted with both compound rests and simple block rests. The rest and tool-holder shown in Fig. 29 is a

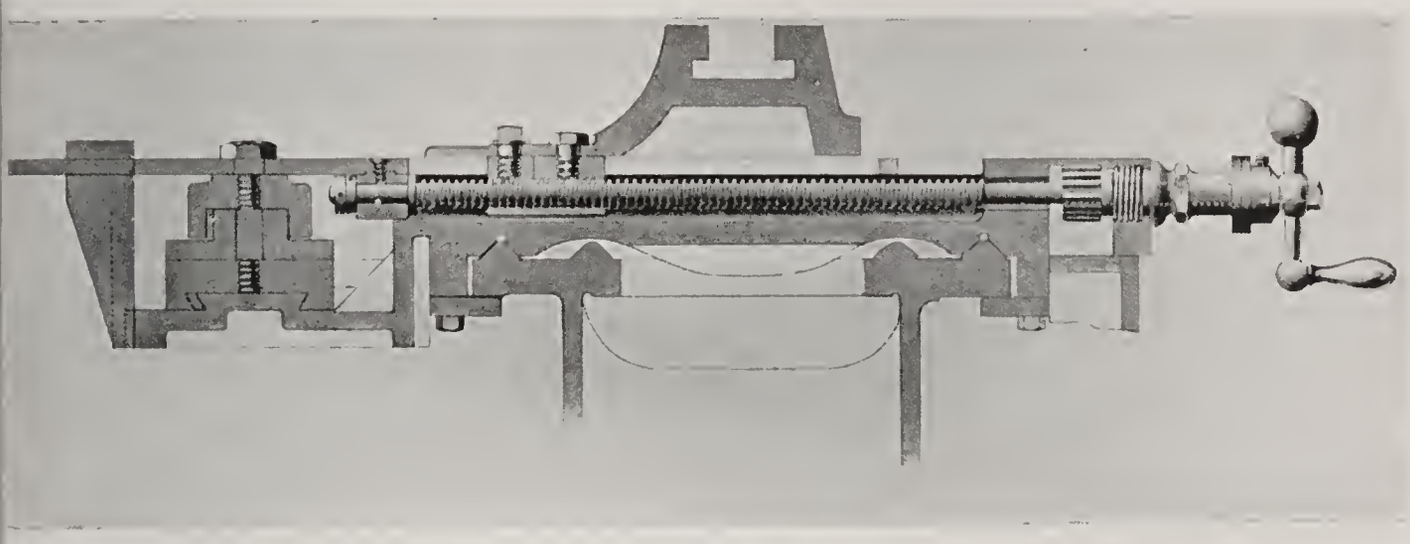

FIG. 35.

CARRIAGE OF BRADFORD LATHE.

good example of what may be expected in large lathes, while most of the other illustrations show the common tool-post with concave ring and elevating wedge. Power cross feed is now the rule where it was once the exception, the screw being driven by a pinion as may be seen in Fig. 35. In most lathes both lateral and cross feeds can be used at once. One convenience that will be appreciated by all operators is the graduation of collars on cross-feed and compound-rest screws, thus furnishing micrometers for the adjustment of the tool.

The general style of rests used on American lathes can be seen from the illustrations and requires no special description.

43. The Apron.

This is the term used by American builders to designate the plate in front of the carriage which contains the actuating mechanism for lateral and cross feeds. Two styles only will be illustrated, and these may be regarded as typical. Fig. 36 shows the interior of an apron where both feeds are actuated

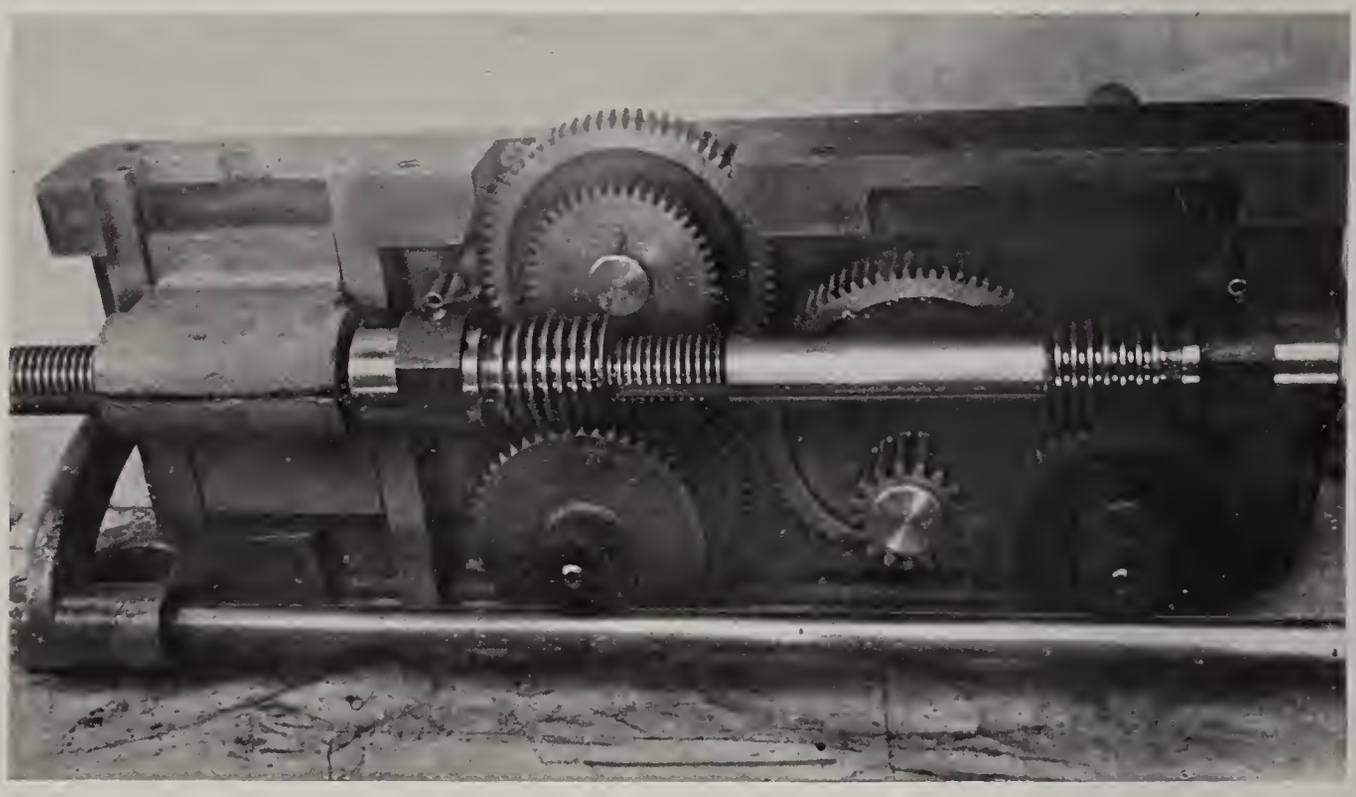

FIG. 36.

INSIDE OF APRON.

The Hendey Machine Co., Torrington, Conn.

by worms sliding on a splined lead screw. For cutting threads the split nut at the extreme left is closed on the screw as shown. The worm at the right through a train of gears drives the rack pinion for the lateral feed, while the one at the centre drives the cross feed in a similar manner. The mechanism is too apparent to need much description. The rod at the lower part of the figure has no connection with the apron mechanism, but is used for reversing the feed gears in the head, as explained in a previous paragraph.

The apron illustrated in Fig. 34 has separate drives for feeding and screw cutting. The lead screw only operates

when the nut at the extreme left is locked, while the feed mechanism is driven by a splined rod running through the bevel pinions shown near the centre.

These pinions and the bevel gear constitute the reversing motion for the feeds and operate both cross and lateral feeds. The rack pinion can be disengaged from the rack when screws are being cut, and suitable locks make it impossible to engage both screw and rod at one time.

On large lathes it is customary to have two bearings to support the rack pinion, one on either side the rack, and for additional rigidity to have the lower edge of the apron bear against a parallel ledge of the bed. Lathes larger than 20-inch of the kind shown in Fig. 26 have these improvements.

All lathes of the ordinary sizes are fitted with an attachment at the rear of the carriage for turning tapers, as it is pretty well understood that setting over the tailstock is an awkward and unworkmanlike method of accomplishing this result. Fig. 35 shows the taper attachment in section. In brief, it may be said that the attachment when in use moves the cross-feed screw endwise without turning it, thereby moving the tool rest. This motion does not interfere in the least with the ordinary use of the cross feed, since the crank shaft telescopes in the screw and drives the latter by a key or spline.

In the best modern lathes the carriage is equipped with the following control levers or wheels all within easy reach of the operator: hand feeds, lateral and cross; power feeds in both directions; feed for screw cutting automatically locked out when other feeds are in use; reverse lever for all or part of the feeds; automatic stop for straight turning.

44. The Tail- or Foot-Stock.

There is but one form of tailstock in general use on American lathes as shown in most of the illustrations.

The 'curved' tailstock, as it is usually called, is so cut away in front as to allow of the carriage being run back against it when the compound rest is set at 90 degrees. It is in two parts, the upper part being adjustable on the lower to offset the tail spindle when desired. The ways for the tailstock may be made in a variety of shapes; the front one may be flat, or the V's may be omitted altogether and the tailstock be guided by bevelled edges inside the bed. This latter arrangement leaves more room for the carriage, permitting a deep and stiffer bridge. The clamping bolt, if but one is used, should be near the front end of the base. In addition to this, a brace or latch underneath may be arranged to engage a rack in the bed and help hold the stock against the thrust of the work.

Lathes such as shown in Fig. 26 have this last-mentioned device.

For moving heavy tailstocks on the ways a pinion engaging with the feed rack is turned by a crank in front as illustrated in Figs. 28 and 29. These figures show the use of two clamping bolts, which is to be recommended for large lathes. The set-over adjustment is sometimes located above the holding-down bolts and independent of them. This combination permits setting over without loosening the base, when heavy work is on the centres.

The tail spindle is actuated by a screw which should have a thread bearing inside the spindle all of the length of the latter except that occupied by the centre. Morse tapers Nos. 4 to 6 are in general use for the centres on both head and tail spindles. It is the general practice to have the spindle clamped near the front end by a split hub and binding screw. This shows in most of the illustrations.

The size of the tail spindle is a matter of nearly as much importance as that of the head spindle, since it is impossible to do work of the full capacity of the lathe unless the supports of the work are rigid and well aligned.

An examination of three makes of lathe such as have

already been referred to in this chapter discloses the following average sizes of tail or dead spindle :—

Swing in inches,	14	16	18	20	24	30	36	42
Diameter of tail spindle,	$1\frac{5}{8}$	$1\frac{7}{8}$	2	$2\frac{1}{4}$	$2\frac{5}{8}$	$3\frac{1}{4}$	4	$4\frac{1}{8}$

45. General Considerations.

A comparison of the lathes illustrated in this chapter with those made in this country twenty or even ten years ago will show improvement along several different lines.

The lathes are heavier and more massive than formerly for the same rated capacity, and the strength and stiffness of the moving parts has increased in proportion. It used to be said with some show of reason that an 18-inch lathe was simply a 16-inch machine blocked up. This criticism no longer holds, and it may safely be said that an 18-inch lathe will turn work up to its full range of swing without trembling or chattering ; and so of the other sizes.

It is, however, in adaptability and convenience of operation that the American lathe is pre-eminent. The combination of gearing for feeds and speeds easily and quickly changed and the reverse motion within easy control of the operator, make it possible to turn out large amounts of product and thereby save in all operating expenses.

The shipping weights of the various sizes of lathes are averaged as follows :—

Swing,	14″	16″	18″	20″	24″	30″	36″	42″
Bed,	6′	8′	10′	10′	12′	12′	12′	12′
Weight in lbs.	1500	2000	2800	3500	5000	8000	11,000	18,000

46. Cutting Speeds.

The speeds formerly recommended were from 20 to 30 feet per minute for wrought iron and soft steel, and somewhat more than this for cast iron. The latter metal has been successfully turned with ordinary carbon steels at a speed of 40 feet per minute.

The use of the new high-speed steels has made a great change in these figures as far as they apply to soft steel, from 80 to 160 feet per minute being not unusual in turning this metal. In turning cast iron the change has not been so great, speeds of from 50 to 75 feet per minute being as high as can be recommended for this material.

Many experiments have been made with the different varieties of air-hardening steels to determine the best steel, the best speed, and the maximum endurance. One of the most complete sets of such tests was made by the Lodge and Shipley Machine Tool Co. of Cincinnati, Ohio, and reported in the *American Machinist* for January 7, 1904. Seven different brands of high-speed steels were tested for endurance and speed, and the two best were then given further tests as to endurance and capacity for removing metal. Table 5 gives a few of the results obtained with the best of the steels tried.

TABLE V

Material Cut.	Number of Cuts made.	Cutting Speed in Feet per Minute.	Depth of Cut in Inches.	Length of each Cut in Inches.	Time of each Cut in Minutes.
Machinery Steel, .	1	201	$\frac{1}{8}$	$14\frac{1}{4}$	1 49
Cast Iron, . . .	1	106	$\frac{3}{8}$	9	2.46
,, ,, . . .	1	94	$\frac{1}{2}$	9	2.46
Machinery Steel, .	9	169	$\frac{1}{8}$	19	1.40
,, ,, . . .	11	155	$\frac{1}{8}$ to $\frac{1}{4}$	3	1.0
,, ,, . . .	16	167	$\frac{3}{8}$	$7\frac{3}{4}$	2.10
,, ,, . . .	16	167	$\frac{7}{32}$	14	3.58

In each instance the tool made the number of cuts recorded without re-grinding and was in good condition at the end of the test. The two runs bracketed together at the last were made by two tools jointly.

Some very interesting experiments along these lines were made in Manchester, England, under the direction of the

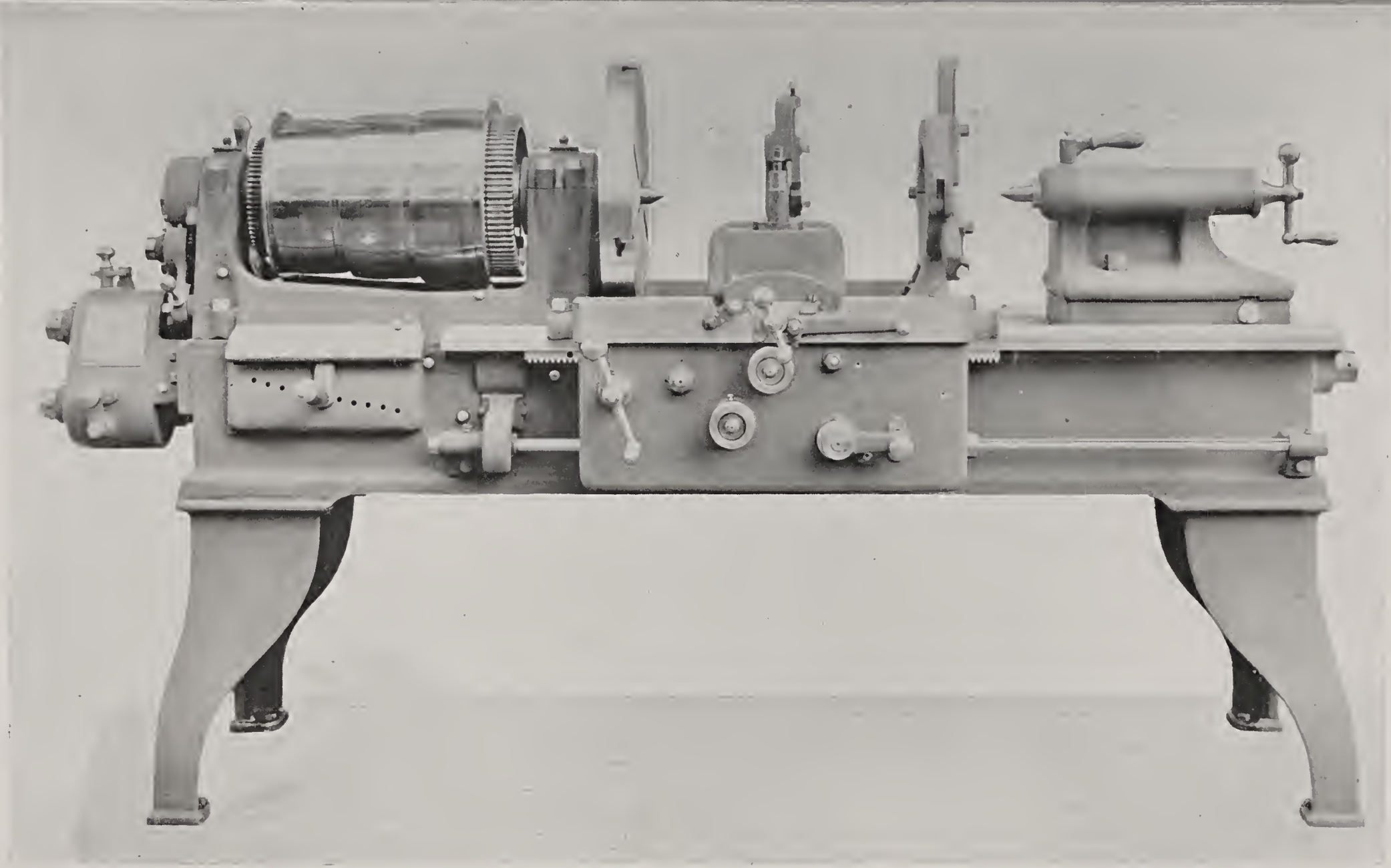

FIG. 37.

HIGH-SPEED LATHE.

The American Tool Works Co., Cincinnati, Ohio.

Manchester Association of Engineers, and reported by Dr. J. T. Nicholson, Professor of Engineering in the School of Technology of that city. It would be impossible to give here even an abstract of these very complete experiments, but it would repay those interested in this subject to obtain a copy of the report. Dr. Nicholson finds the maximum allowable speed to depend upon the area of cut and the nature of the material machined, and gives the following formulas as representing approximately the relations.

Let v = cutting speed in feet per minute and a = area of cut in square inches, *i.e.* product of depth of cut by feed, then—

For soft steel, . . .	$v = \frac{1{\cdot}943}{a + 0{\cdot}011} + 14$
For medium steel, . .	$v = \frac{1{\cdot}823}{a + 0{\cdot}016} + 5$
For hard steel, . .	$v = \frac{1{\cdot}77}{a + 0{\cdot}027} + 5$
For soft cast iron, . .	$v = 115 - 13a$
For medium cast iron, .	$v = 63 - 858a$
For hard cast iron, . .	$v = 40 - 400a$

Dr. Nicholson further found that a speed of 90 feet per minute could be maintained on soft steel, and that the new steels would cut about four times as fast as the ordinary steels. He found no tool which would run two hours at a speed of 34 feet per minute on medium cast iron. On the whole, the speeds given in this report are considerably less than those reported from the Cincinnati tests.

Some actual examples of work in railroad shops are given in the *American Machinist* of March 5, 1903. In one case two tools removed 62·5 cubic inches of metal per minute from a 9-inch forged steel shaft at a cutting rate of 125 feet per minute. This would be at the rate of over 1000 lbs. per hour.

Another rapid-reduction lathe made by the Lodge-Shipley Co. with three cutting tools removed 113 cubic inches per minute from 50 carbon steel or at the rate of nearly 1900 lbs. per hour. The cutting speed in this instance was 50 ft. per minute.

A study of the results obtained with the new steels in everyday service leads to the following conclusions: that in turning soft and medium steels, cutting speeds of from 80 to 120 feet per minute are easily maintained; while for finishing, speeds of from 160 to 200 feet per minute are not uncommon. That cast iron is a more difficult metal to treat, the limit being from 50 to 75 feet per minute for roughing and somewhat more for finishing. The use of the high-speed steels and the resulting increase in the amount of metal removed per hour necessitates a change in the design of the machine itself. It must not only be strong and rigid in all its parts, especially so in the spindles and the carriage, but it must also have greater driving power.

Fig. 37 illustrates a lathe designed for this class of work. It possesses the usual conveniences for rapid work such as have been enumerated in this chapter, and is furnished with spindles and carriages of extra strength.

Its principal peculiarity, as may be seen from the cut, is the large belt contact on the cone pulley. The steps are only three in number, and are wide enough to accommodate a 4-inch double belt. The back-gear ratio is only 2·13 to 1, and a two-speed countershaft is employed, giving twelve changes in all. The highest speed is only four times the lowest, and all are so graduated as to give a cutting speed of approximately 160 feet per minute on work from one inch to four inches in diameter.

The important fact to be noticed in this connection is that belt power is what determines the cutting power, and that no ratio of gearing will enable the machine to do its work if the belt is not large enough.

47. Horse-Power of Lathes.

It is frequently desirable to know the probable power required by machine tools when planning a shop or factory, especially if electricity is to be used as a motive power.

The General Electric Co. published in the *American Machinist* for April 30, 1903, a list of sizes of electric motors as installed by them for driving machine tools. In this list are given the following sizes for engine lathes :—

	H.P.
Speed lathes,	1
22″ and 24″ lathes,	2
26″ and 30″ ,,	$2\frac{1}{2}$
36″ and 42″ ,,	$3\frac{1}{2}$
48″ and 54″ ,,	5
60″ lathes,	6
72″ ,,	$7\frac{1}{2}$
84″ ,,	10

These sizes are given as the result of tests made on machines in everyday service, but would not apply to lathes where high-speed steel is employed on roughing work.

Experiments made by the writer on small lathes with ordinary tools have shown an average of about one-half a horse-power consumed by lathe and cut when removing from 10 to 20 lbs. of cast iron per hour, the lathes being from 16 to 22 inches swing.

Reports of tests by Professor John J. Flather give about the same results.

Some tests conducted at the Baldwin Locomotive Works on electrically-driven lathes showed the following power consumption :—

Kind.	Size.	Material Cut.	Number Tools.	Horse-Power : Total when Cutting.		
				Min.	Max.	Avge.
Wheel Lathe,	84 in.	Cast iron	2	2·9	7·9	6·1
,, ,,	84 in.	,, ,,	2	4·2	5·8	5·1
,, ,,	84 in.	,, ,,	2	5·3	6·2	5·8
,, ,,	90 in.	,, steel	2	...	...	6·38

The issue of *Machinery* (New York) for March 1903 contains quite complete reports with regard to the horse-power of the machine tools in two American railway shops.

In the new shops of the Union Pacific R.R. at Omaha, Nebraska, electric motors are used on all the tools, and the following powers have been selected for engine lathes :—

Size of Lathes.	H.P. of Motor.
16 in. × 6 ft.	1 to 2
18 in. × 8 ft.	2
20 in. × 10 ft.	$2\frac{1}{2}$
22 in. × 12 ft.	2
24 in. × 12 ft.	$2\frac{1}{2}$
26 in. × 12 ft.	$2\frac{1}{2}$
30 in. × 14 ft.	$2\frac{1}{2}$
36 in. × 16 ft.	3
42 in. × 16 ft.	3
80 in. driving wheel lathe,	$7\frac{1}{2}$
90 in. ,, ,, ,,	15

Tests of machine tools in the locomotive shops of the Buffalo, Rochester and Pittsburgh R.R. showed the actual power absorbed by various engine lathes to be as follows :—

Kind of Lathe.	Size of Lathe.	Number of Tools.	Horse-Power.	
			Starting.	Cutting.
Wheel	42 in.	one	4·6	0·5
,,	79 in.	two	...	4·0
Engine	28 in.	one	4·7	2·5

The wide difference between the power required for starting and for steady running will be noticed. This points to one advantage of the group system in driving machine

tools, since it will not often be the case that all the machine will start at once and a smaller motor can be used.

Experiments made by the writer on lathes of from 14 to 22 inches swing, using one tool of ordinary steel, gave the following as the horse-power for cutting metal: where w = weight of metal removed per hour :—

H.P. = ·035 w for cast iron.
H.P. = ·067 w for machinery steel.

To this must be added the horse-power required to run the machine itself, which should be not over 0·1 h.p. for the machines mentioned.

Experiments made with the air-hardening steels and high speeds naturally show a great increase in the power required.

The tests made by the Lodge-Shipley Company which have already been alluded to showed the limits to which this can be carried. One of the Company's special high-speed lathes of 20-inches swing, using self-hardening steel and cutting at the rate of from 121 to 175 ft. per minute, consumed from 7·1 to 15·9 horse-power on different cuts. This included the power required to run the counter and the lathe itself. The material cut was machinery steel, the depth of cut $\frac{1}{16}$ inch, and the feed from $\frac{1}{16}$ to $\frac{1}{5}$ inch. With deep cuts a greater horse-power even was recorded, in one instance reaching 30 h.p.

The following table presents a summary of some tests on large lathes made under the direction of the writer and reported in *Cassier's Magazine* for December 1903 :—

TABLE VI.—SUMMARY OF TESTS IN THE SHOPS OF THE LAKE SHORE AND MICHIGAN SOUTHERN RAILWA

Machine.	Duration of Run, Min.	Material Cut.	Horse-Power.		Metal Removed.		Horse-Power (Net)	
			Total.	Net.	Total Pounds.	Per Hour Pounds.	Per Cu. In. per Min.	Per Lb. per Hour.
42 in. × 18 ft. triple-geared engine lathe, turning steel axle, motor 10 h.p., at 850 rev. per min.,	12·6	Steel	2·57	1·29	8·53	40·6	0·466	0·032
	5·0	,,	4·09	2·78	5·3	63·4	0·686	0·044
	2·8	,,	...	...	0·73	15·6	...	...
	11·75	,,	2·62	...	8·30	42·4	...	...
	33·5	,,	8·55	...	28·9	51·8	...	...
	11·0	,,	1·34	...	0·79	4·3	...	...
	14·0	,,	0·89	...	0·795	3·4	...	...
42 in. × 16 ft. triple-geared engine lathe, 10 h.p. motor,	14·5	Cast Iron	1·65	...	0·80	3·33	...	...
	12·5	,,	1·64	...	0·60	2·89	...	...
	34·5	,,	1·69	...	3·28	5·70	...	...
42 in. car-wheel lathe, 20 h.p. motor,	14·1	Steel	5·35	3·54	126·0	53·6	1·11	0·066
84 in. driving-wheel lathe, motor 15 h.p., at 800 rev. per min.,	120·5	,,	5·33	3·92	218·7	109·0	0·61	0·036
	155·0	,,	3·02	1·366	66·0	25·5	0·907	0·053
86 in. triple-geared engine lathe, motor 7·5 h.p., at 675 rev. per min.,	22·0	Cast Iron	0·937	0·475	4·98	13·6	0·545	0·035
	7·0	,,	1·57	1·01	3·75	32·2	0·485	0·031
	5·75	,,	1·44	0·88	3·55	37·0	0·371	0·024
	3·5	,,	1·65	1·04	1·05	18·0	0·890	0·057
	3·42	,,	0·88	0·32	1·88	33·1	0·151	0·010
28 in. to 48 in. extension gap lathe, motor 7·5 h.p., at 875 rev. per min.,	22·0	,,	0·74	0·21	0·48	1·31	2·45	0·160 [1]
	22·0	,,	0·70	0·17	0·51	1·4	1·88	0·121 [1]
	24·0	,,	0·75	0·22	1·8	4·51	0·746	0·048
	8·0	,,	1·17	0·63	1·37	10·32	0·957	0·061
	6·5	,,	1·31	0·77	1·38	12·72	0·947	0·061
	3·0	,,	0·77	0·23	0·30	6·06	0·588	0·038

[1] Inside cut.

The machines in this case were doing the ordinary work of the shop, and no attempt was made to crowd them. Self-hardening steel was used for all the tools, and the machines were driven by independent motors. For further particulars the reader is referred to the journal mentioned.

48. Electric Drives.

The problem of driving by electric motors is simpler in the case of lathes than in that of reciprocating machines like planers and shapers, since electricity is best adapted to producing continuous rotary motion.

For small lathes the group system of driving has several advantages. This method usually involves the use of a short line shaft driven by a motor and sufficient for perhaps five to ten machines each having its separate countershaft. If the lathes are of the same size and have a reversing mechanism independent of the countershaft, one long counter may be used for the group with friction clutches over each machine, thus doing away with the line shaft and its friction. The group system permits the use of constant-speed motors of a larger size, and at the same time divides the large starting torque so as not to be felt so much by the motor.

Where there are no large machines and the group system is used exclusively, two-phase or three-phase alternating current can be employed at some saving of time and repairs.

Machines requiring more than two or three horse-power can be equipped with separate motors to advantage, thus securing a certain amount of flexibility as regards arrangement and electrical speed-control. In such case direct-current motors are to be used, and by the combination of controller variation and mechanical means a large number of speeds may be easily secured.

As has been noted in the case of planers, several different methods of mounting and connecting the motors have been

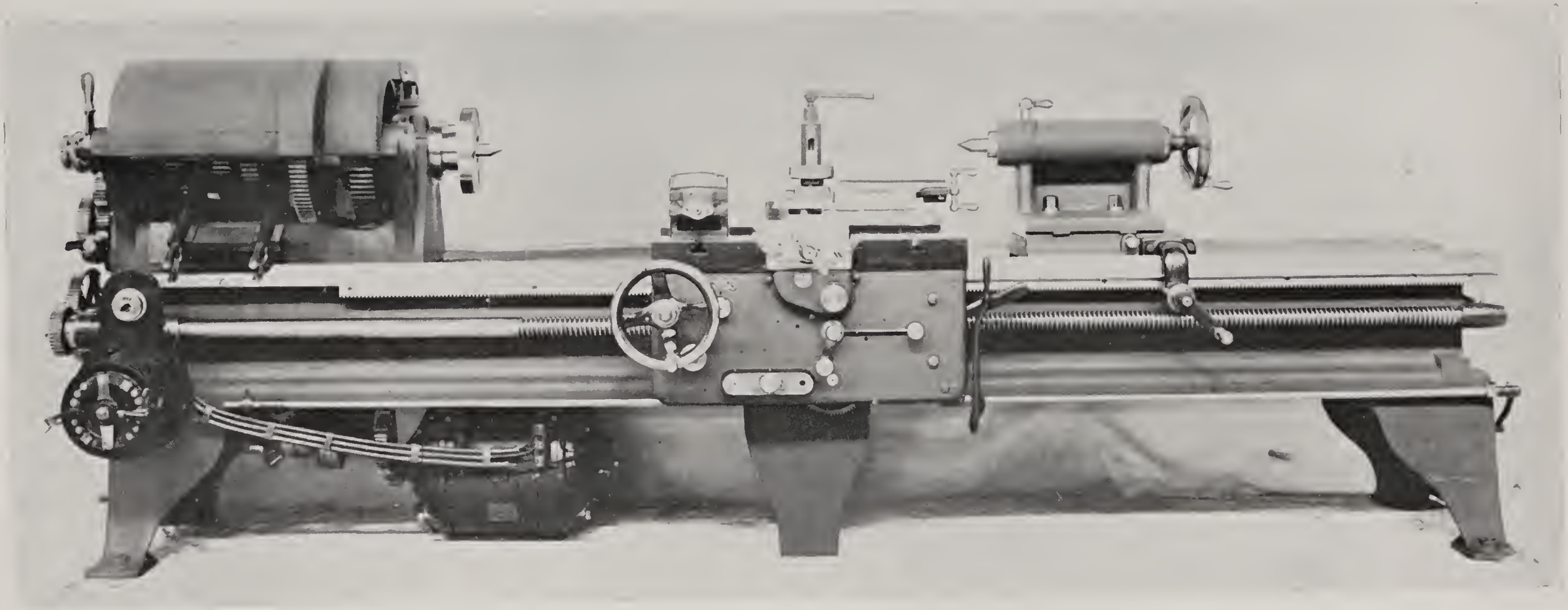

FIG. 38.

24-INCH LATHE, ELECTRICALLY DRIVEN.

The Prentice Bros. Company.

employed. One lathe has a motor bolted to the rear of the head cabinet and connected by a belt to a countershaft swinging on arms just above. This arrangement is compact and allows of the use of a constant-speed motor, but the cone belt connections would seem to be rather short for the best efficiency. The sizes of motor recommended, run by even gradations from 2 horse-power for an 18-inch lathe to 6 horse-power for a 36-inch lathe. (Compare with recommendations of the General Electric Co. in the preceding section.)

Connection of the motor by gearing is the more common arrangement as being most economical of room. The motor is usually mounted above the headstock and gears to a quill on the spindle; by means of a variable-speed motor with controller and the usual back gearing a wide range of speeds can be obtained. The controller is located on the carriage, putting the speed-control within easy reach of the workman.

Fig. 38 shows an ingenious application of a constant-speed motor to a lathe, the changes of speed being effected entirely by gearing. As may be seen, the motor is hung underneath the bed of the lathe and connects with the spindle by a train of gears. The regulation of speed is effected by means of the levers shown projecting from the headstock, while the reversing motion is underneath and controlled directly from the carriage.

Comparing this method with that just described, where a variable-speed motor is employed, the greater complication of the mechanical control is evident.

Electrically the constant-speed motor is simpler and more efficient, but all things being considered, it would seem as if electrical control was more convenient for the operator and represented a more advanced stage of development in the application of electricity.

Fig. 39 shows the application of a variable-speed motor driven by the multiple voltage system, to the 27-inch lathe. As a motor of this type must furnish the power required to run

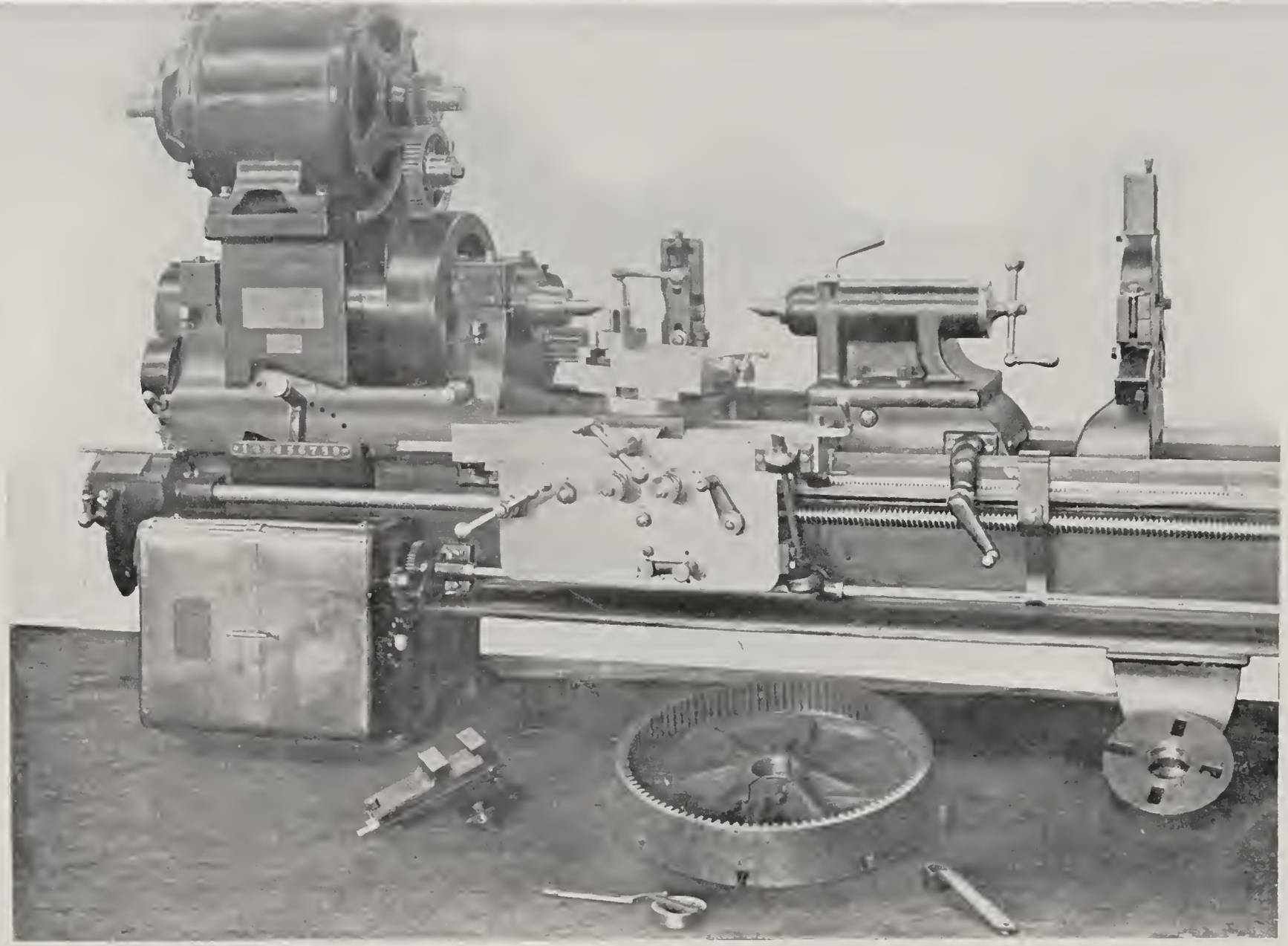

FIG. 39.

27-INCH LATHE—ELECTRICALLY DRIVEN.

Lodge and Shipley Machine Tool Co., Cincinnati, Ohio.

the machine at its lowest speed, a much larger motor is necessary than when a constant high speed is employed. For instance, in the case of the machine just mentioned the powers of the motors at normal speed and high voltage would range from $3\frac{1}{2}$ horse-power for an 18-inch lathe to 18 horse-power for a 36-inch lathe, being from two to three times the sizes required under the other system.

CHAPTER IV

SPECIAL LATHES, INCLUDING TURRET LATHES

49. Gap and Extension Lathes.

The same general remarks made in Chapter I. with regard to widened planers are applicable to gap lathes. Increasing the swing of the lathe without strengthening the parts to correspond, and with the intent to deceive the customer, is bad engineering and bad business.

Some manufacturers of cheap machinery in the past have tried to do this, and to foist upon their customers 18-inch lathes which had been 'raised' from 16-inch, on much the same principle that unscrupulous rogues raise bank notes from ones to tens. Such deceivers can never prosper in the long-run, and sooner or later lose reputation and trade.

To-day the tendency is to cut down rather than to raise, and the 'heavy' 16-inch lathe has the strength and weight of the former 18 or 20 inch. The gap or extension lathe is not an attempt to deceive any one; it is avowedly a compromise and stands for what it is.

The large manufacturers, having a great variety of machines, may have no use for such. A lathe which tries to turn 18-inch work and 36-inch work will probably not be quite as efficient for either as if it had been designed for one alone. But the small or medium shop, especially the job-shop, is usually in need of just such machines. A limited number of tools with the widest possible range is the requirement.

Fig. 40 illustrates the usual arrangement in machines of

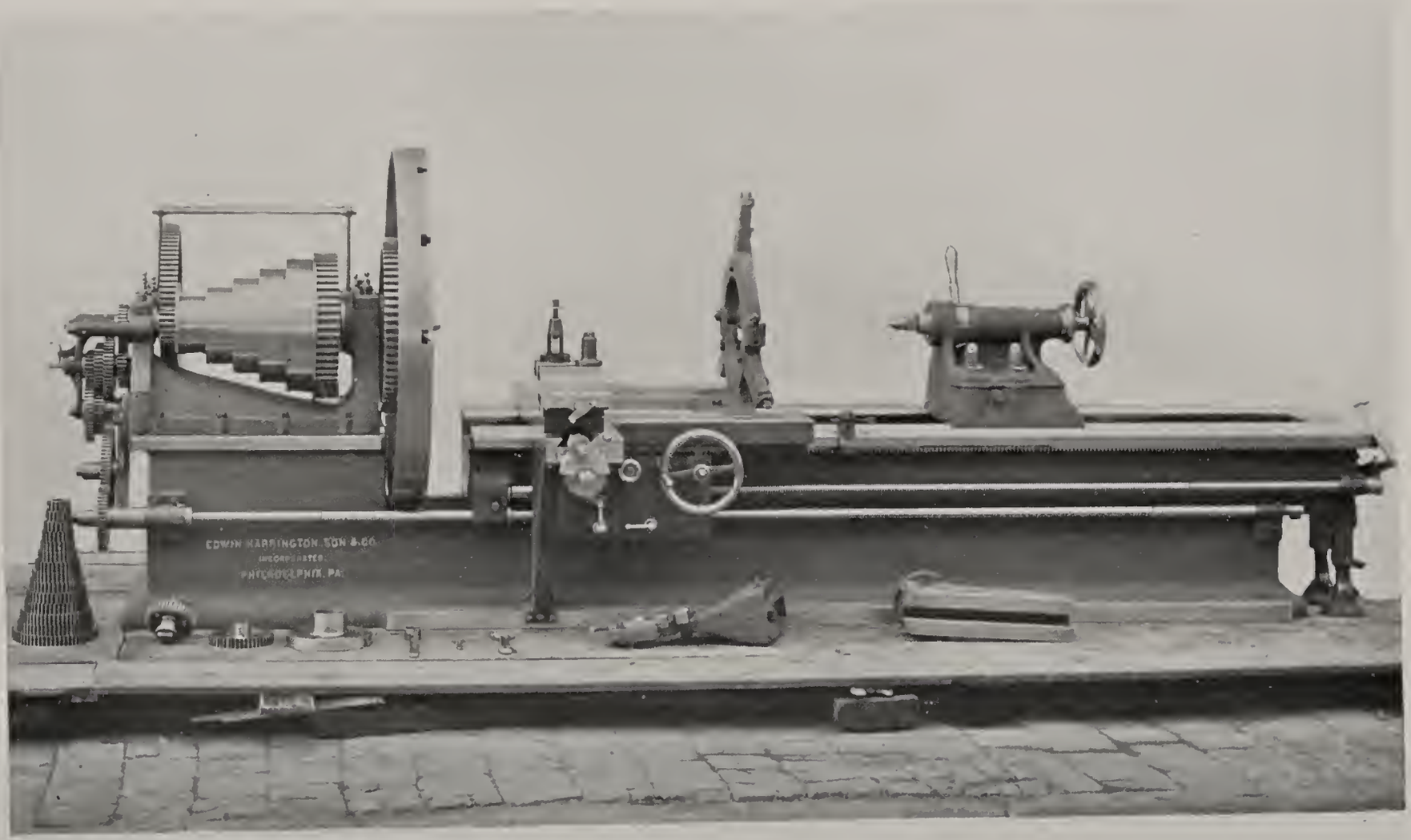

Fig. 40.

28-INCH × 48-INCH EXTENSION LATHE.

Edwin Harrington, Son and Co., Philadelphia, Pa.

this kind, the gap being obtained by sliding back the top half of the bed on longitudinal ways when large work is to be swung. The gap can thus be made wide or narrow as occasion demands, and the extension bed is then firmly bolted to the bottom bed.

The carriage has a front extension supported by a sliding bracket for use at the full swing of the lathe. By extending the bed to its full length and supporting it with the jack-screws shown it is possible to turn long shafting. The lathe shown is triple-geared, and the size and weight of the heads and carriage are such that ordinary work can be done effectively at the largest swing.

50. Two-Spindle Lathes.

The lathe shown in Fig. 41 offers another solution of the problem of killing a large bird and a small bird with the same stone. This machine is designed on the same general lines as a lathe of the smaller swing but with all its parts unusually massive. Supplementary head and tail spindles are provided above and to the rear of the ordinary spindles, such as to give about double the normal swing above the bed. A supplementary tool-post and the necessary gearing for the head completes the equipment. When in use for ordinary work the machine is to all intents and purposes a 26-inch lathe, the supplementary parts being entirely out of the way. When used at its full capacity it is a 48-inch lathe from head spindle to foot spindle, not so heavy nor so strong, perhaps, as the standard 48-inch machine, but strong enough for emergency work. It will be noticed that at the larger swing the face plate is directly geared.

51. Reduction or Roughing Lathes.

In shops where large quantities of heavy work are done, a simple lathe of unusual weight and power in proportion to

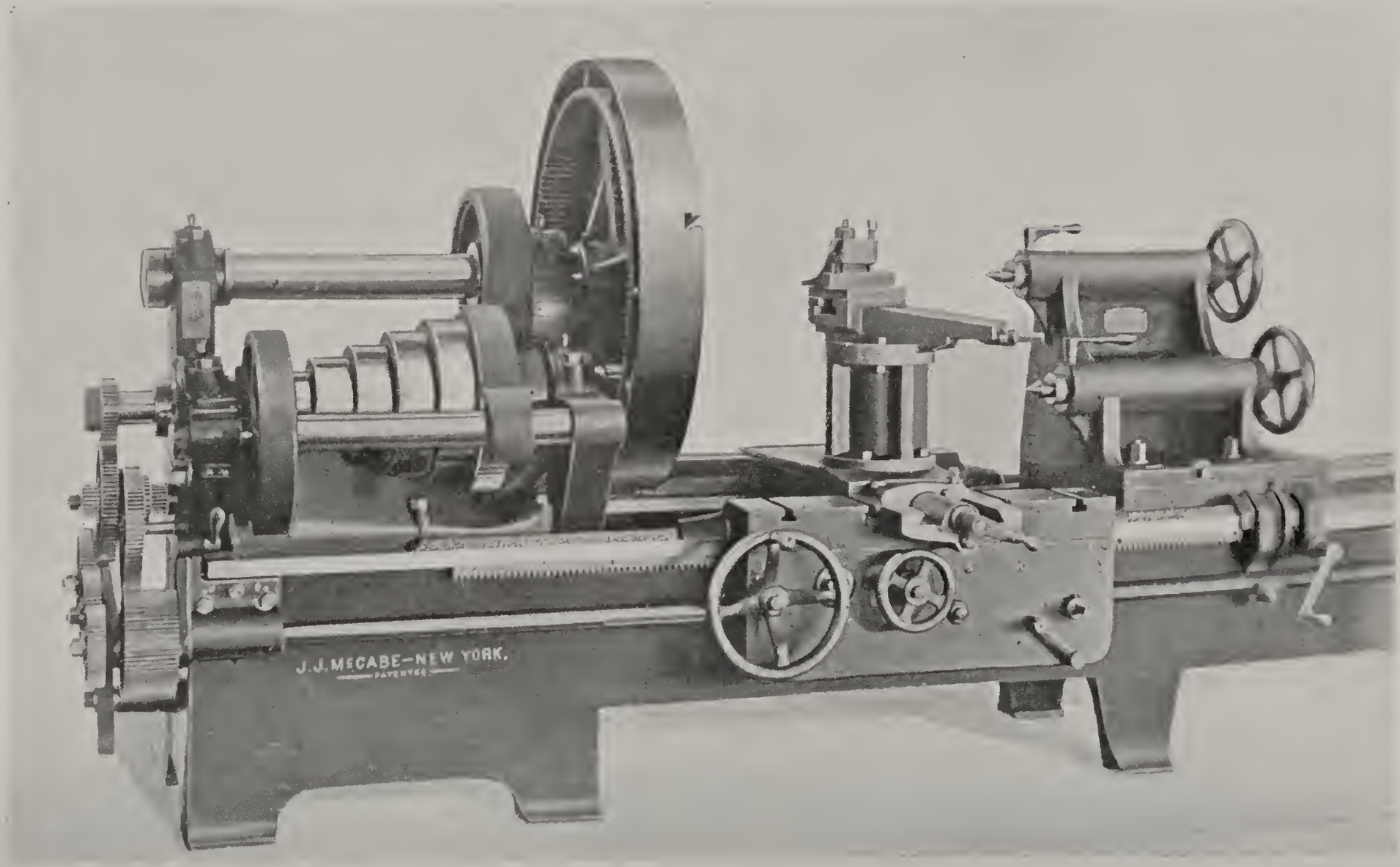

FIG. 41.

26-INCH AND 48-INCH DOUBLE SPINDLE LATHE.

Messrs. J. J. M'Cabe, New York City.

its swing is a useful tool. Such a machine is to have a limited range of work, but it is to do that work in less time than is possible on the standard all-round machines.

The Draper 18-inch reduction lathe is driven by a 6-inch double belt, and has four changes of back gears in the head and two speeds available from the countershaft, giving ten speeds in all. The lathe is adapted to turning steel from one

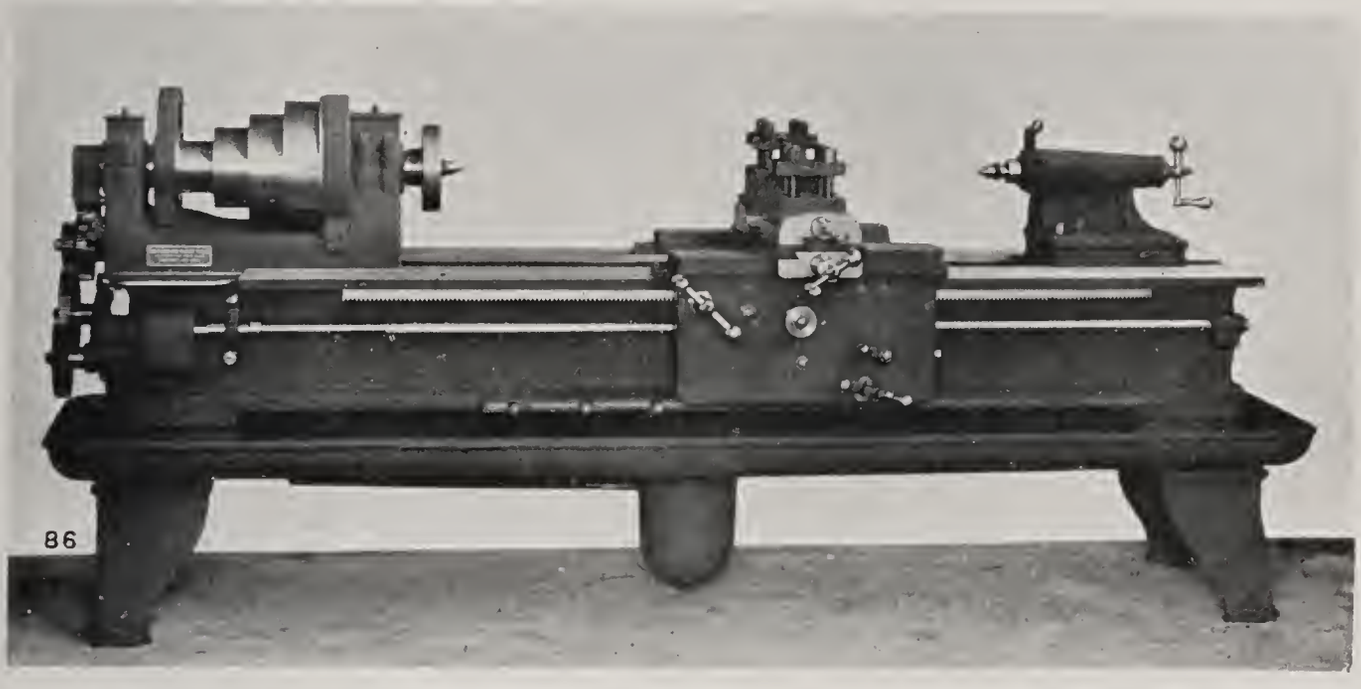

FIG. 42.

ROUGHING LATHE.

The R. K. Le Blond Machine Tool Co., Cincinnati, Ohio.

inch to six inches in diameter, and is intended particularly for use with self-hardening steel tools.

Another lathe of this type is shown in Fig. 42. The belt power is not as great, apparently, as in the preceding machine, there being four steps on the cone. The heads and spindles, however, are made heavier than usual, and the ways are widened to give more support for the carriage. Special pains have been taken with the carriage and the tool-holders to have them rigid enough for the work the lathe is expected to do. The high-speed lathe illustrated in Fig. 37 is also an example of this type of machine.

52. Stud and Bolt Lathes.

Somewhat akin to the reduction lathe in simplicity and adaptation to special work are the single-head stud lathes, as they are usually termed. This latter type of machine is intended for plain turning on short pieces which are to be made in large quantities. Such a lathe is well adapted for work which is too long to be successfully handled on the turret lathe. Like the reduction lathes it has a large belt contact, but unlike them has no back gears. The screw-cutting mechanism is left out, thus doing away with complication of gearing; and the beds are short, ranging from 4 to 6 feet. The lathe usually has an automatic stop on the feed motion so that it may be used for turning up to a shoulder.

53. Tool-Makers' Lathe.

Fig. 43 shows a type of lathe designed for use in the tool-room on work which calls for an unusual degree of accuracy. This machine makes the tools which make the work, and any error here would appear in the work, perhaps in a magnified degree. Lathes of this class are expensive and not intended for general use. The bearings of all sorts are generous in size and finished with special care. The lead screw is large in diameter, and has a very small limit of error. The carriage is guided by one large V at the front and a flat bearing at the back to ensure good alignment. The lathe has a large number of special attachments, which fit it particularly well for the varied service of the tool-room.

54. Facing Lathes.

For short work of large diameter this class of lathe is well adapted. The tailstock and the screw-cutting mechanism are omitted, and the work is held entirely by the clutch or face plate. Two tool-posts are used, making it possible to

turn and face work at the same time. The carriage is wide and heavy, with special T-slots for attaching the tool holders. The cone pulleys on the spindle and those used for driving the feed are larger than usual and have steps for wide belts,

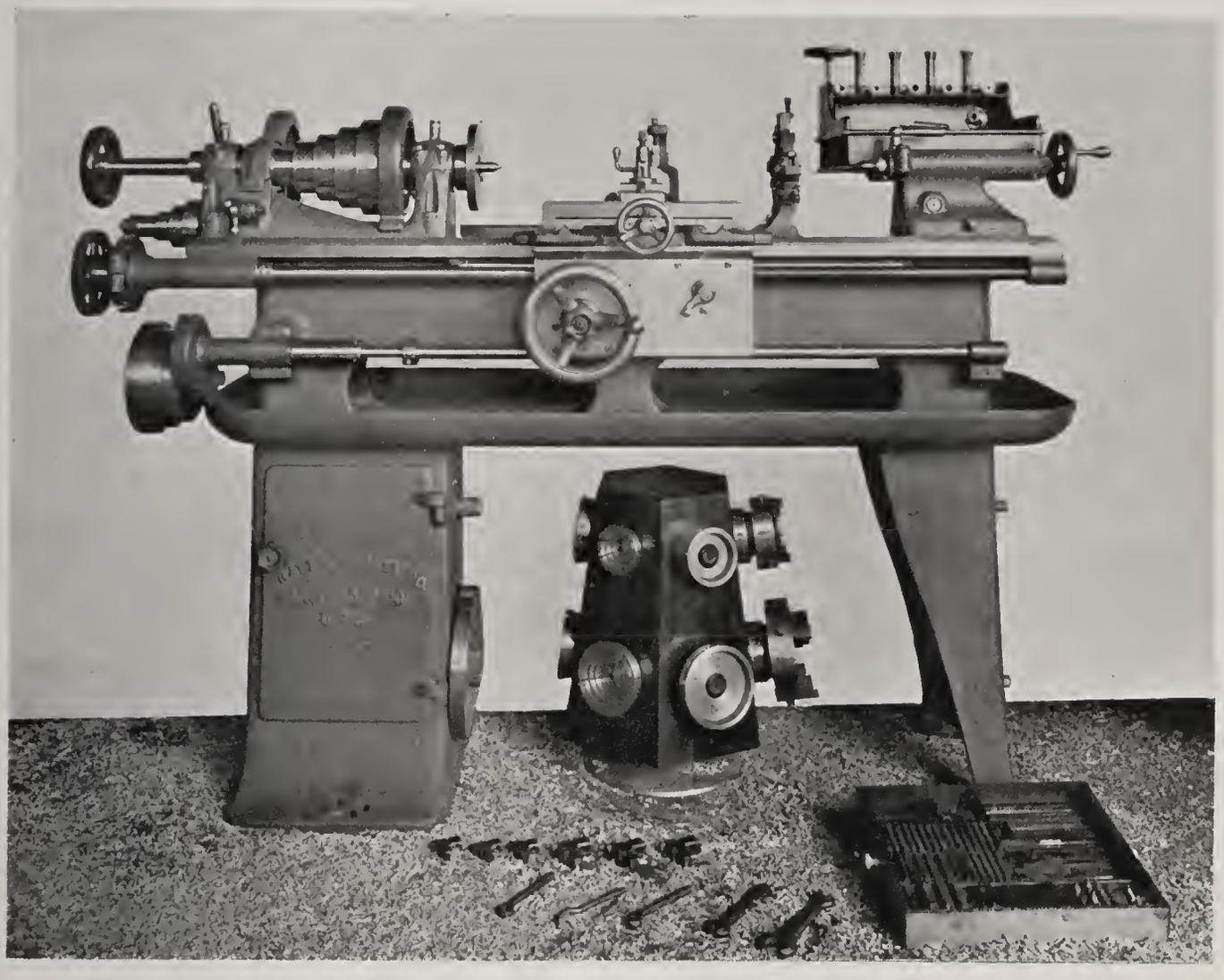

FIG. 43.

TOOLMAKER'S LATHE.

The Pratt and Whitney Co., Hartford, Conn.

thus making it possible to take a full cut at the extreme swing of the lathe.

It is but fair to remark, however, that vertical boring mills are to a large extent replacing lathes for this class of work.

55. Railroad Machinery.

Besides the special lathes which have so far been mentioned, there are others which are restricted to an even

narrower range of work and have no place in the general machine shop. But brief mention can be made of such in a general treatise.

The manufacture of locomotives and other railway machinery has resulted in the specialising of tools to an extent seldom seen elsewhere. The enormous number of locomotives and car axles made in this country has necessitated a special lathe for this class of work. Like the roughing lathes which have been shown, this machine is massive and adapted for heavy cuts at a high speed. To permit of the use of two tools, the axle turns on two stationary centres and is driven by a rotating head in the middle. In every sense of the word this is a special machine.

The same may be said of car-wheel and driving-wheel lathes, which are adapted only to this one class of work. Fig. 44 illustrates a 100-inch driving-wheel lathe and needs but little explanation. The size of the wheel to be turned makes it necessary to drive from both ends of the axle at once. The two large face-plates shown are accordingly driven in unison by gearing with one pinion shaft underneath. The tool-posts are also in duplicate and especially designed for the very limited service of the lathe.

56. Miscellaneous.

The shafting lathe is a machine which is of the same special character as railroad machinery and not adapted for use in general shops. Its extreme length and its lack of adaptability render it a sort of white elephant in the ordinary machine shop. On the other hand, it would be foolish to think of turning shafting in the old-fashioned machine at a sacrifice of both quality and quantity of work.

The speed lathe or hand lathe used for finishing and polishing work at a high speed is so simple in its construction as to need no description.

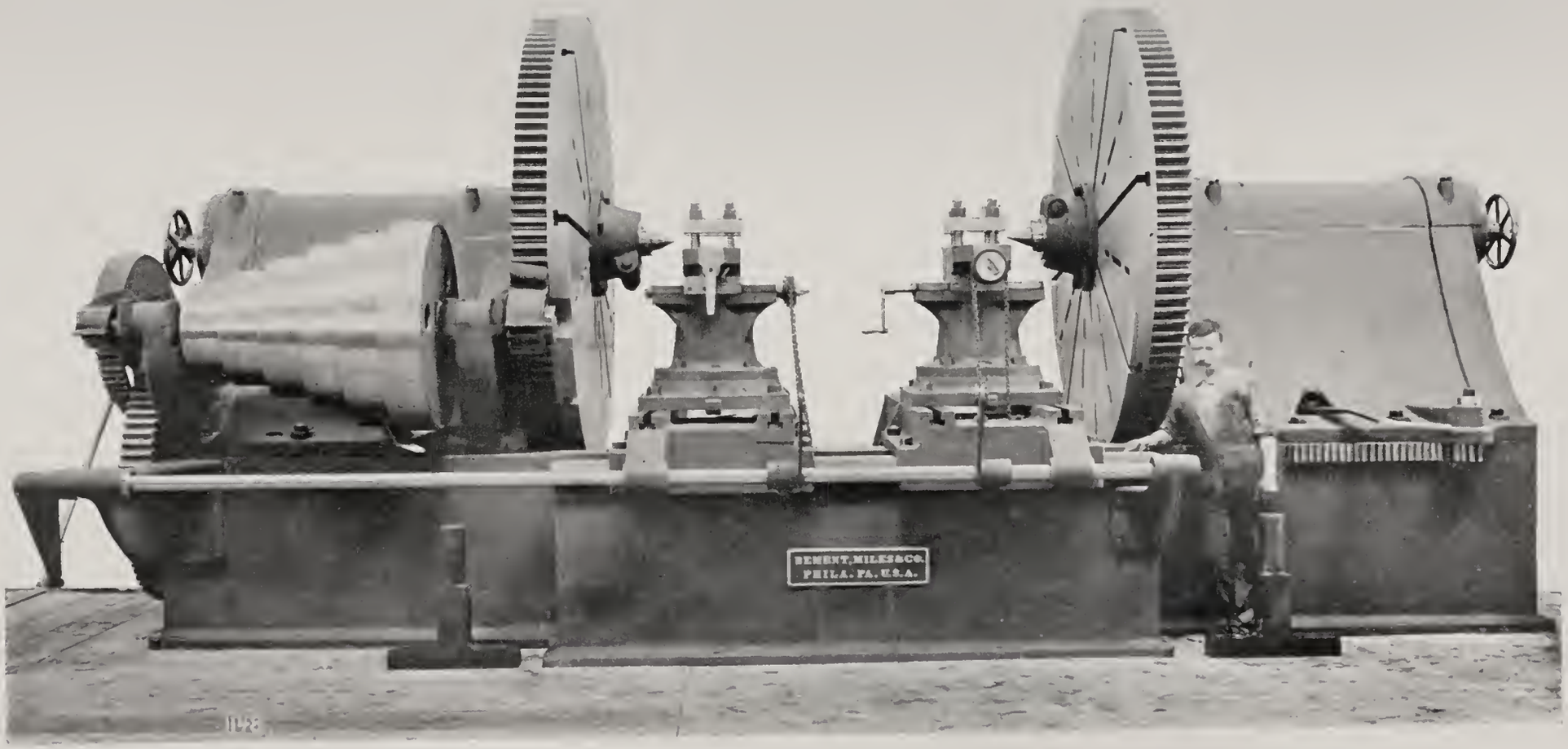

FIG. 44.

100-INCH BEMENT HEAVY DRIVING-WHEEL LATHE.

Niles-Bement-Pond Co., New York.

57. Turret Machinery.

The necessary duplication and interchangeability of parts on small machine work has led to the quite general adoption of turrets carrying several forming tools, which are used in succession on the piece to be finished. This method permits of great speed in handling and machining the work, and at the same time ensures accurate duplication of parts.

The turret may be used as an attachment to an engine

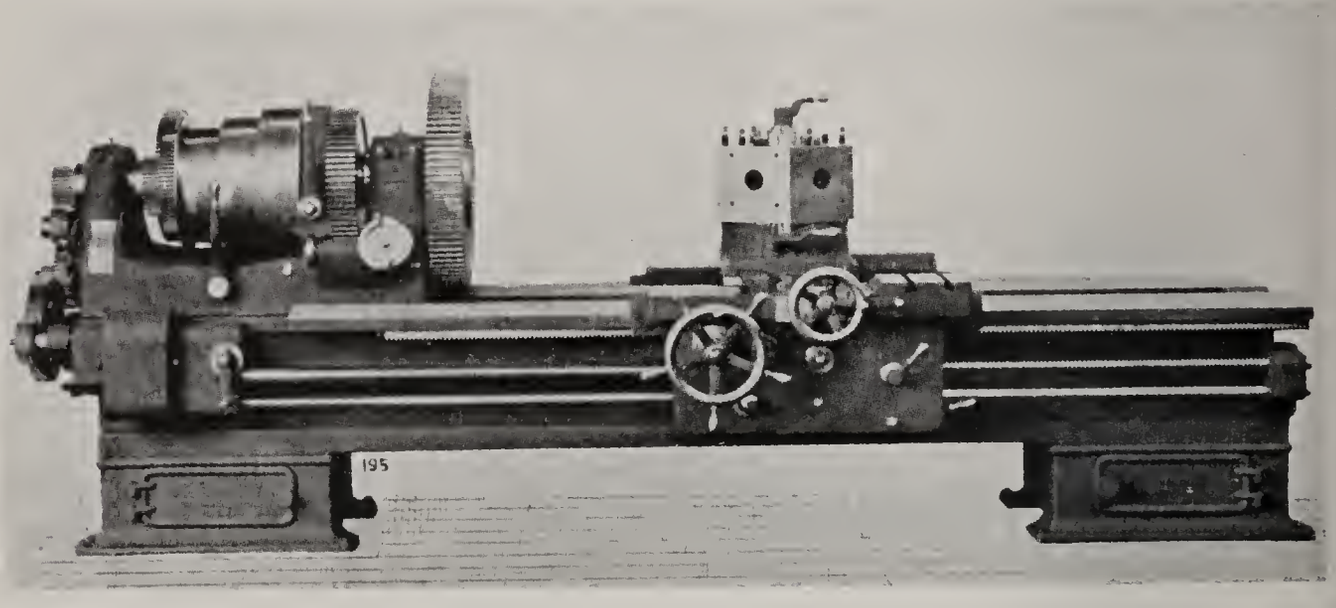

FIG. 45.

ENGINE LATHE, WITH TURRET ON CARRIAGE.

The R. K. Le Blond Machine Tool Co., Cincinnati, Ohio.

lathe, in which case it may take the place of a tailstock or may be fastened to the carriage. In the former case the usual carriage is retained, and its tools may be used as in ordinary work. In place of the foot block or tailstock a shoe is clamped to the ways of the lathe, and on this moves the slide carrying a turret with sockets for six tools. The slide is operated by a turnstile, and the turret is turned either by hand or automatically. The power feed for the turret mechanism is independent of the carriage feed, so that both sets of tools may be operated at once, each with the feed best adapted to the work. In selecting a lathe for this class of work special attention must be paid to the main spindle, since these

are subject to much greater wear than when the lathe is used for ordinary turning.

Fig. 45 shows an 18-inch engine lathe equipped with turret mechanism on the carriage, a special cross-slide being provided on which the turret revolves. This lathe has the usual longitudinal feed, power cross-feed and screw-cutting attachments, and is well adapted for short chuck-work where turret tools take the place of the compound rest.

In this machine, as in that just described, either the turret machinery or the usual tailstock and compound rest may be employed, making it a sort of combination tool. Such a lathe is useful in small shops doing miscellaneous work, where the expense of separate turret machines might be prohibitive.

58. The Turret Lathe.

The application of turret attachments to engine lathes is profitable under the circumstances just mentioned, but must be regarded as a compromise. Wherever there is work enough to keep a turret machine running continuously, it is better to install a lathe specially designed for this class of turning. A good example of the turret lathe pure and simple is shown in Fig. 46. A machine using so much oil as is necessary in forming and chucking steel should have a pan to catch the drip. Stiffness and perfect alignment are essential in turret work, hence the casting of headstock, bed and pan in one piece. Reversing the cone pulley and putting the small step in front also makes it possible to stiffen the headstock at this point. For similar reasons the turret slide is located directly on the bed of the lathe, which is specially designed for this purpose. The lathe shown will take stock up to 1 inch in diameter and finish up to 10 inches in length. Fig. 47 shows clearly the shape of slides used, which are such as to ensure uniform wear on flat and on bevelled surfaces, and adjustment without loss of alignment. A turnstile is used for moving the slide, but a lever may be substituted when

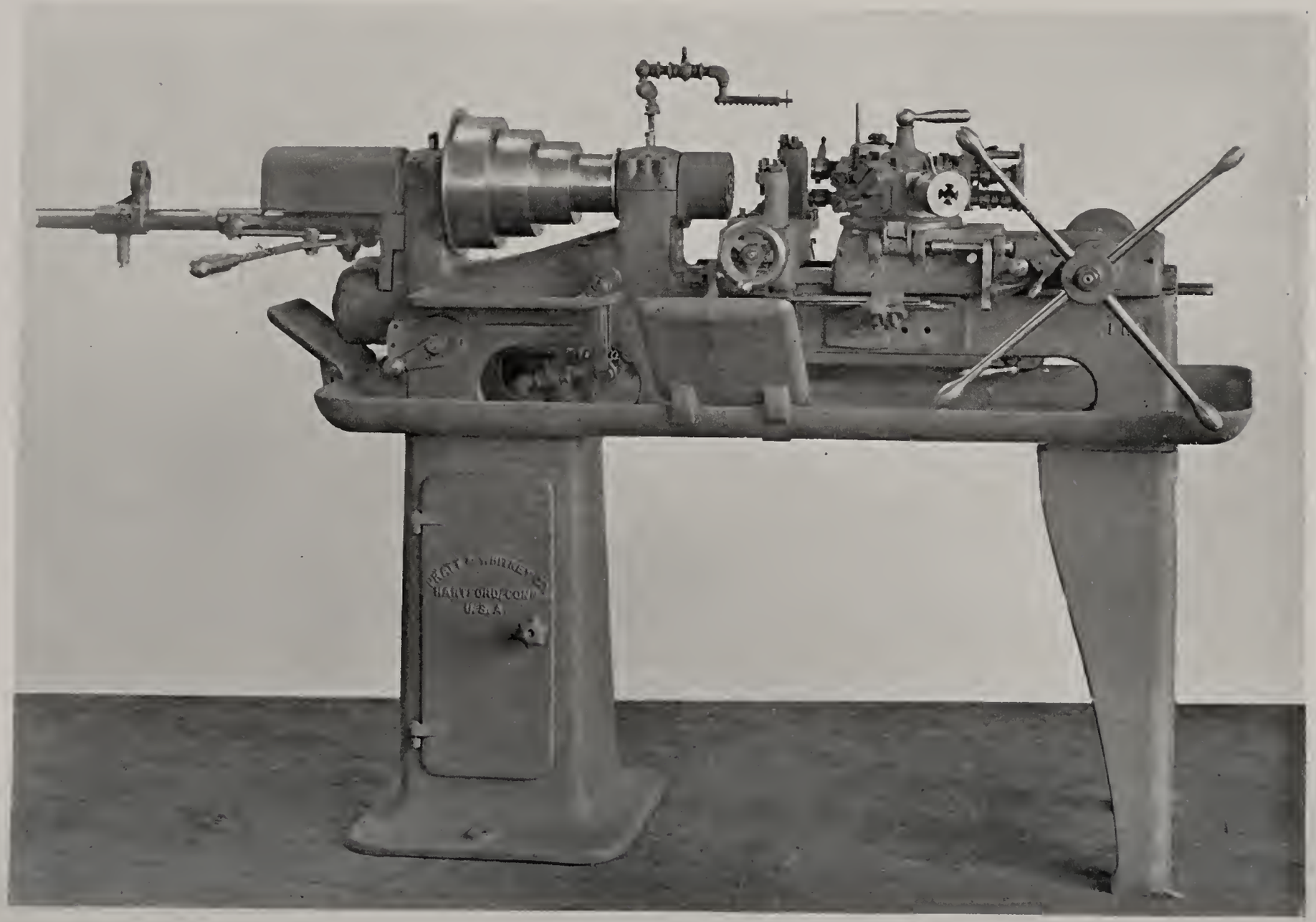

FIG. 46.

1-INCH × 10-INCH TURRET LATHE.

desired. The steel rods which act as stops for the turret slide may be seen in either figure; as the turret turns into position an arm or lever hinged to the slide is moved automatically by a cam so as to strike the end of the proper rod. The locking of the turret itself takes place directly under the tool in use at the time, as is right. The indexing mechanism for the turret can be readily thrown out of gear when it is desired to use only two tools. Without any sacrifice in convenience of operation, the turret and slide seem to have the least number of pieces and joints possible and consequently to be rigid and accurate.

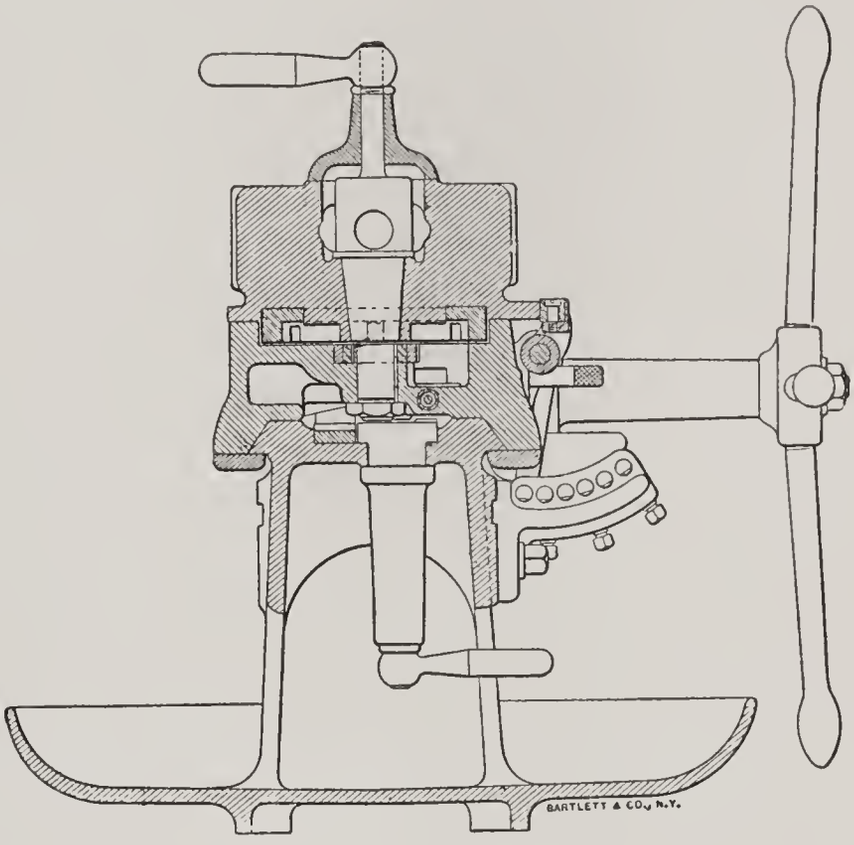

Fig. 47.

Traverse Section of New Model Turret Lathe at Centre of Turret.

The Pratt and Whitney Co.

A double cross-slide is used with forming and cutting-off tools, one in front and one behind the work. The slide can be located anywhere between headstock and turret slide and clamped to ways the same as those shown in Fig. 47. The tool-posts have each two screws for clamping the tool, and are so made that the tool may be raised or lowered bodily or set at an angle.

Two means are provided for operating the cross-slide, a lever connected to pinion and rack for use with cutting-off or narrow tools and a hand-wheel turning a screw for wide tools which require a slow feed.

The collet or chuck for holding the tool is operated by the same lever that advances the rod, and is so constructed that

in closing it does not move the work forward or back. The feed for the rod has double the throw of the closing mechanism so as to feed long work with but one motion of the lever.

Oil is fed from the pan to the tools by a rotary pump at the rear of the headstock.

59. Hollow Hexagon Turret.

Fig. 48 illustrates a somewhat larger and heavier machine than that just described. This lathe is triple-geared, has a swing of 16 inches over the ways, and will handle 2-inch round stock up to 24 inches in length. The head is cast solid with the bed, and the latter rests on a line bearing at the turret end so that the machine will adapt itself to irregular foundations without springing. The jaws of the chuck and the rod feed are operated by the longer vertical lever in front of the head. The roller feed for the stock can be used when the machine is running or when it is at rest.

The turret is of the hollow hexagon type turning on a saddle which is gibbed directly to the bed of the machine. This saddle slides on large V's, and is fed automatically by means of a rack located in the top of the bed directly under the cutting tools so as to avoid twisting strains. The three feeds available are controlled by a nest of gears, and the changes can be made without stopping the machine. The hollow hexagon form of the turret permits of securely fastening the several tools from the inside and leaves the outside free for other mechanism. The motion of the turret is automatic, being controlled by the backward motion of the slide or saddle.

The stops for the turret slide are located on the front of the machine in such a position as to be free from chips and dirt, and so arranged as to furnish three different stops for each face of the turret.

No carriage is used with this type of lathe, since the style of turret described permits of attaching all turning and

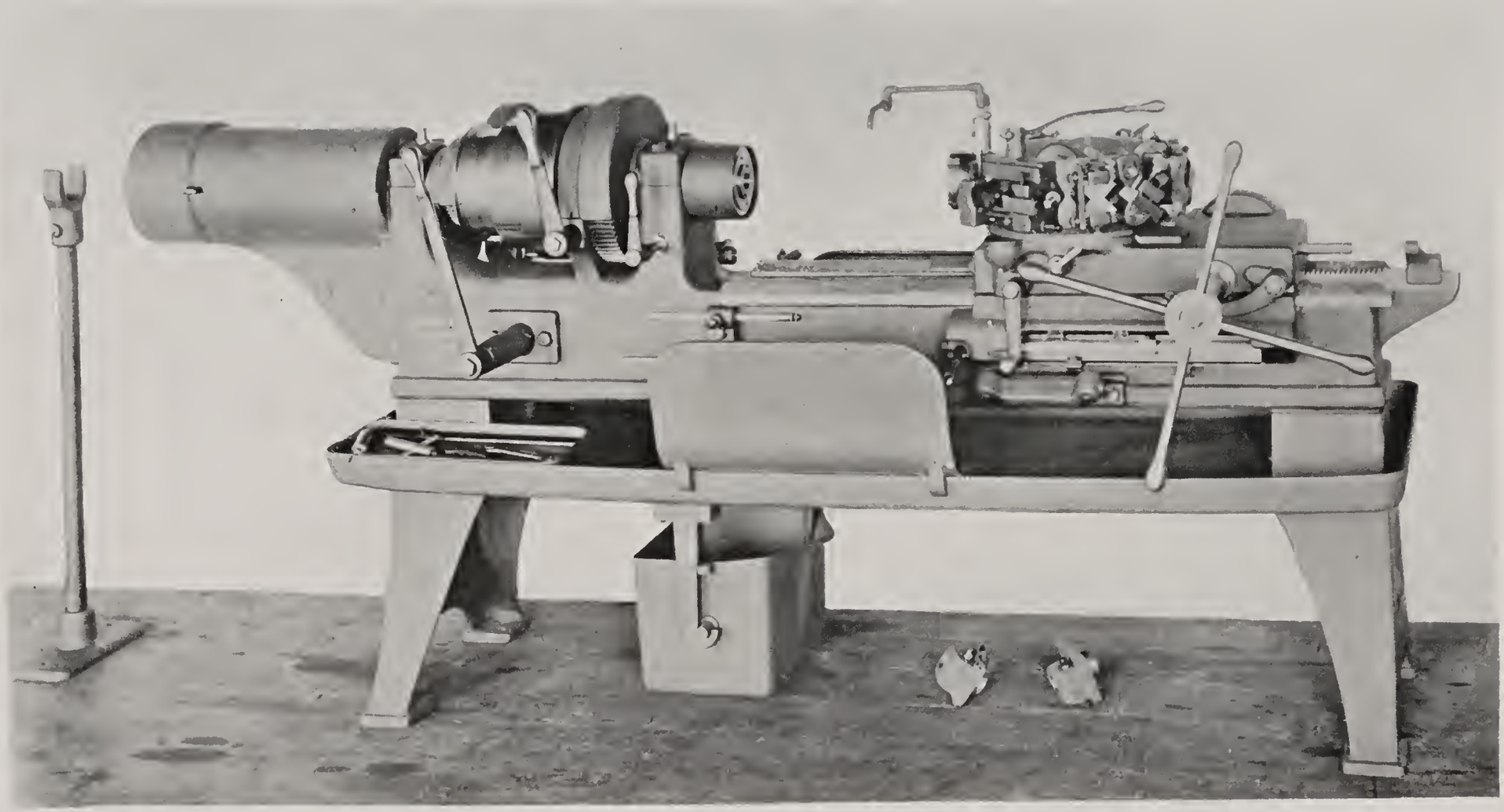

FIG. 48.

2-INCH × 24-INCH HOLLOW HEXAGON TURRET LATHE.

The Warner and Swasey Co., Cleveland, Ohio.

cutting-off tools directly to turret. In the form of cutting-off tool used, the cross-slide is manipulated by a lever at the top having adjustable stops at the bottom. The oil spout in this machine is carried by the turret slide so as to always be above the cutting tool, and the oil flows continuously, whether the machine is running forwards or backwards.

60. Flat Turret Machine.

The machine shown in Fig. 49 differs from those already described in the shape of the turret, which is of the so-called Hartness or flat type. It consists of a flat, circular plate mounted on a low saddle and carrying the various tools and tool holders on its upper surface. The principal advantage claimed for this type of turret consists in the fact that the tools do not overhang but have an unyielding support directly under the cut. Furthermore, the turret plate itself is secured to the saddle by an annular gib, thus clamping it rigidly to the saddle at all points. The turret is automatic, turning as the tool clears the work, and may be so set as to skip one or more of the indexing positions when desired. The locking bolt is on the outer edge directly under the cutting tool. There are six feed-stops for the saddle, or one for each face of the turret. These are located on the top of the bed. The saddle slides on V's, is gibbed to the outside of the bed, and has a power feed operated by a feed rod and rack somewhat similar to those of an engine lathe.

Back gears and triple gears are furnished for the head, giving either 4 to 1 or 16 to 1 ratio as desired. The gearing is in the head below the main spindle. As may be seen from the cut the cone has but three steps, and these are unusually wide, giving good belt power. The machine is intended to handle work up to 2 inches in diameter and 24 inches long, but it can be used for chucking pieces up to 14 inches in diameter. The general arrangement of bed and headstock

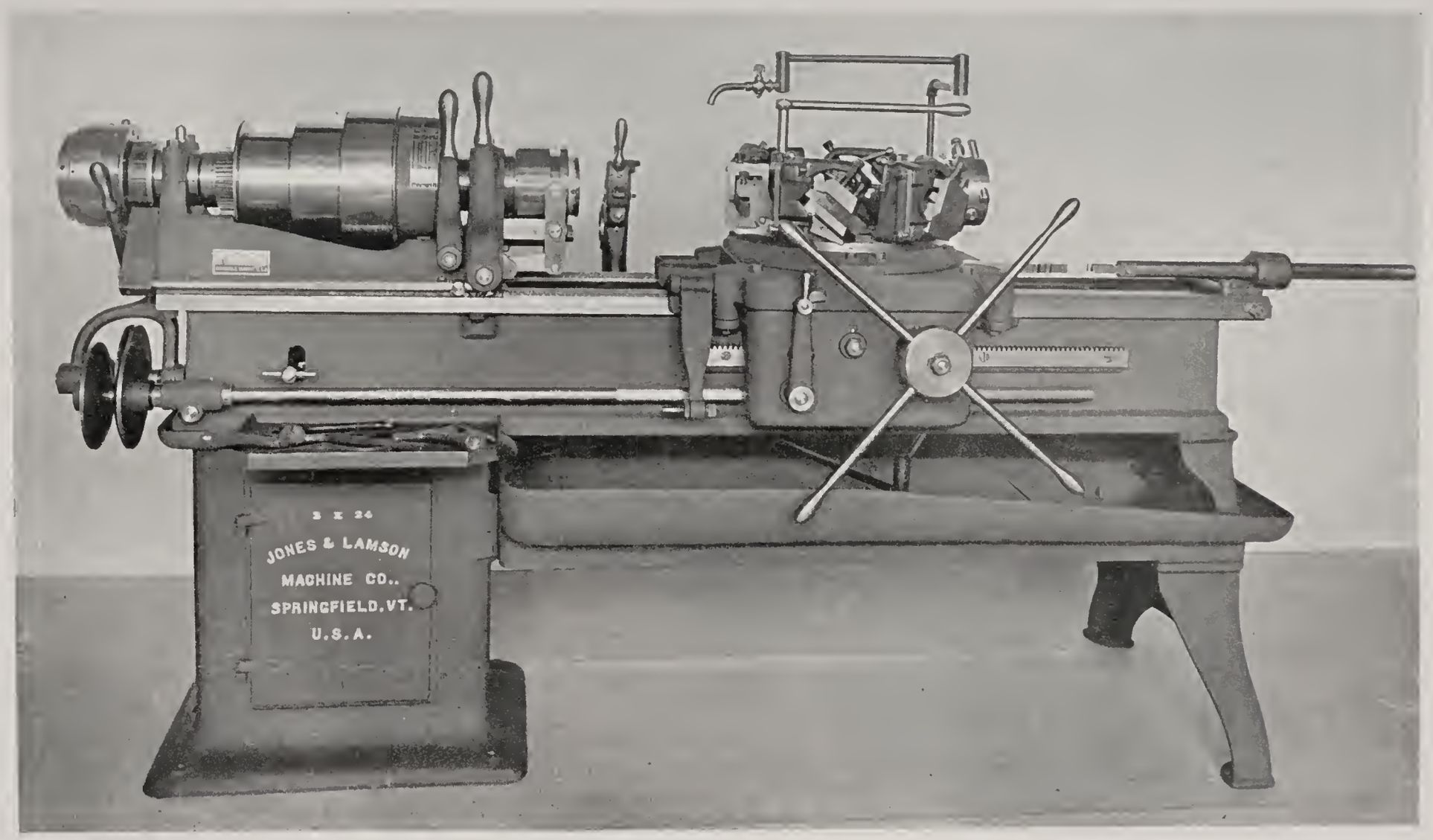

FIG. 49.

FLAT TURRET MACHINE.

The Jones and Lamson Machine Co., Springfield, Vermont.

are more like those of an engine lathe than most of those shown in this chapter.

The collet or chuck will hold any shape of rough stock firmly, and the roller feed permits of advancing and gripping the rod without stopping the machine.

The feed is actuated by the power of the machine, and is set in motion by the same lever which controls the chuck. This lever may be seen at the front of the head in Fig. 49.

The machine just described is particularly well adapted to turning and threading large studs and bolts cut directly from the rough stock. Samples of work done by the regular outfit of tools accompanying the machine include studs of machinery steel from $1\frac{1}{4}$ to $1\frac{3}{4}$ inches in diameter and varying in length from 3 to 6 inches, which were finished in from 7 to 20 minutes each. The work on each stud included turning to four different diameters and cutting one or more screw threads. Bolts from 2 to 6 inches long and $\frac{1}{2}$ to $\frac{3}{4}$ inch in diameter have been finished in from 2 to 7 minutes each. A limit of variation in size of one quarter of a thousandth of an inch is practicable.

The characteristics of turret machinery which have made such speed and accuracy possible are in the main as follows :— Rigidity in turret, tools and head, coupled with good alignment. Automatic setting of turret and of carriage in the exact position for work. Simplicity in the movements required for setting and clamping stock. The possibility of making speed and feed changes without stopping the machine. Last, but not least, the free supply of oil to the cutting tool so as to flood the work and carry away heat and chips promptly.

61. Automatic Lathe or Chucking Machine.

The turret lathes so far described are intended for cutting up and forming steel rod into studs, collars, sleeves, etc., and are expected to handle material up to 2 inches in diameter. Turret work is not by any means confined to these limits, and

it has been found just as profitable to turn forgings and castings of a larger size in a similar manner.

Lathes for this latter class of work are frequently called chucking machines, since the separate pieces operated on are usually held in a chuck and finished inside and out. A heavy machine of this type is capable of machining castings 24 inches in diameter. The use of wide forming or shaving tools necessitates massive construction and powerful gearing. The bed must have unusual depth and weight with a head cast directly to the bed. One such machine made by the American Turret Lathe Co. has four changes with double gearing, besides two with quadruple, making six in all, the ratios varying from 5 to 83.

In the quadruple gearing a steel pinion engages directly with the rim of the chuck. The saddle is gibbed to the bed of the lathe and has unusually long bearing surfaces. It can be operated by a hand-wheel in front of the machine, but when in use is moved by a power traverse having a speed of 25 feet per minute. Eight different feeds are provided, and screw threads can be cut from 2 to 30 threads per inch.

The turret is a hollow octagon with one side cut away for the cross-slide, which carries a tool-post. There are five tool holders on the turret itself, and several supplementary holders are used above the work. This lathe is well adapted for machining castings up to the full swing of the chuck.

Some idea of the capacity may be obtained from considering a cast fly-wheel 16 inches in diameter finished in such a machine in one and a half hours, or one-third of the time required to finish on an ordinary engine lathe. Piston heads, stuffing boxes, gears, cone pulleys, etc., can be finished completely and in much less time than by former methods.

62. Turret Tool-Post Lathe.

The machine illustrated in Fig. 50 is intended for handling the very largest work which it is practicable to

finish in a turret lathe and will swing pieces 34 inches in diameter. A gap lathe of this same size swings 50 inches in the gap.

The peculiar features of this lathe are the inclined position of the turret and the use of an intermediate turret capable of carrying four tools.

The bed and headstock are cast in one piece; the spindle is very large, having a $4\frac{1}{4}$-inch bore, and the cone is fitted for a 6-inch belt. The spindle has a friction back-gear, operated by the upright lever shown in front, and a pinion gearing direct to the chuck for unusually large work. Like the lathe described in the preceding article, this machine is intended principally for operating on castings or forgings held in the chuck and not for cutting from the solid stock.

Both the tool-post carriage and the turret saddle slide on V's similar to those of an engine lathe and are secured by gibs underneath the ways. The main turret is hexagonal and, as shown in the cut, so inclined as to throw the tools in front up out of the way of the operator. The size of the turret permits of the use of quite elaborate turning and forming tools for various classes of work.

The traverse of the turret slide in the machine illustrated is 72 inches, and it can be moved by hand or by power. There are four reversible feeds for each carriage, and when desired a power quick-return is furnished for the turret slide.

Independent stops are provided for each of the six faces of the turret, and also for each of the four tools on the intermediate carriage. This latter is a feature somewhat different from any so far described. It is a carriage similar to that of the engine lathe with longitudinal and transverse power feeds. Instead of the ordinary tool-post it is equipped with a turret having places for four separate tools and capable of being turned on a vertical axis. The tools in this turret can be adjusted independently for height, and are well adapted for turning and facing the outside of large work, while the

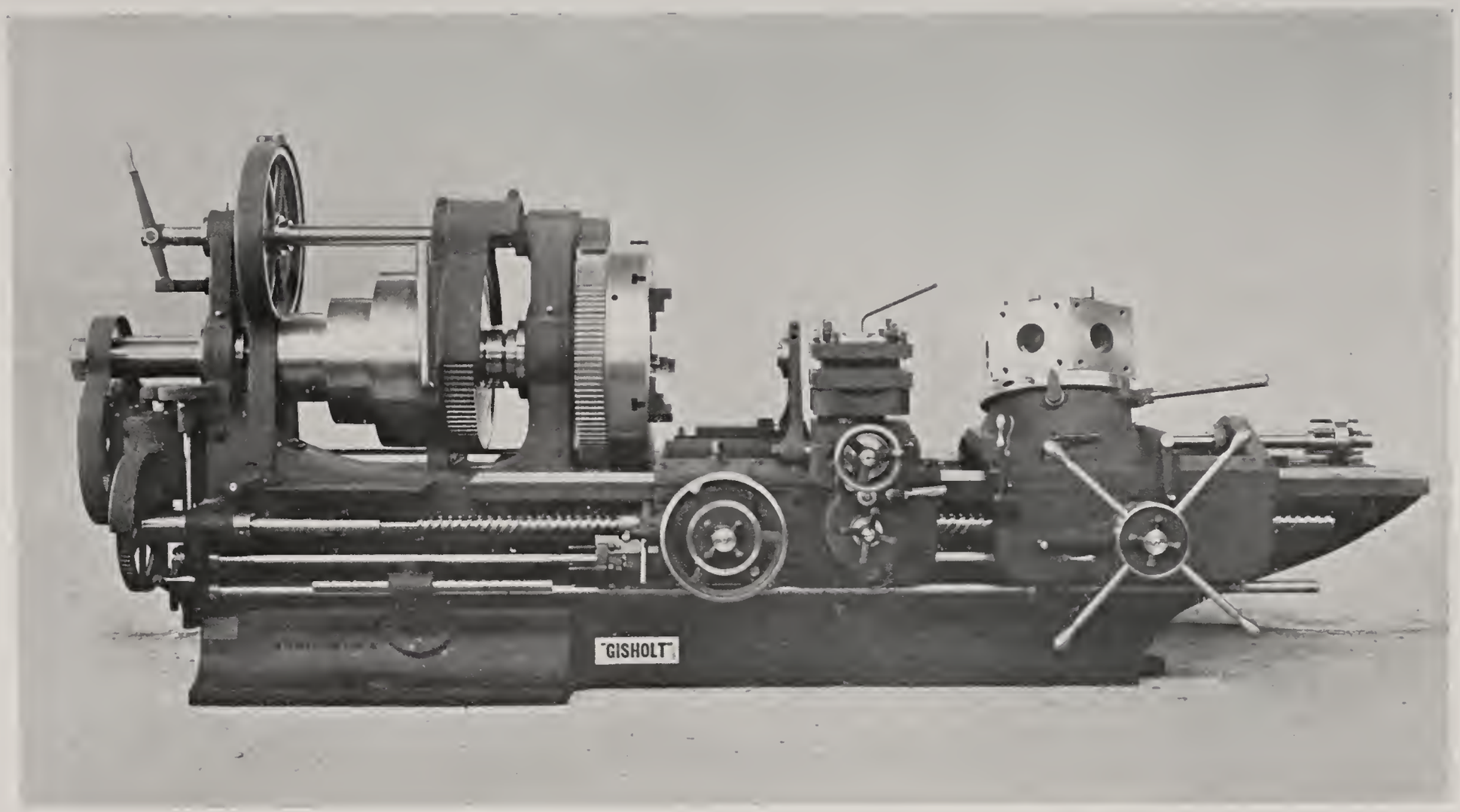

Fig. 50.

34-INCH TURRET LATHE.

Gisholt Machine Co., Madison, Wisconsin.

other turret is used for boring and for facing nearer the centre. The four tools on the tool-post in combination with the six on the large turret make it possible to finish quite complicated castings or forgings without change of tools. The power of the lathe is such that wide shaving cuts can be taken without difficulty.

The machine seems well suited for finishing such pieces as pistons, cylinder heads, flanges, couplings and pulleys up to the limits given by the size of the machine.

63. Forming Machines.

The lathe generally known as a forming machine is one in which the tool is as wide as the work is long and reduces the latter to the required shape at one operation. While it is evident that the work can be rapidly finished in this way, it is also manifest that the machine must be powerful, and that the work must be securely held. Fig. 51 illustrates a machine of this character intended for unusually heavy work, and capable of forming from the rough bar pieces 3 inches in diameter and 5 inches long.

The machine is massive in construction, has a long and large spindle, and carries a cone with wide steps, but gearing is unnecessary with the sizes of stock used. To prevent overhang and ensure firm support to the work, the end of the spindle itself is enlarged and threaded inside to receive the collet which grips the stock. The chuck is thus practically a part of the spindle. The carriage of the machine carries a slide on which are mounted the forming cutters, one for roughing and one for finishing. An independent slide carries a cutting-off tool.

The turret slide can be equipped with a drilling attachment as shown in the cut, or with the ordinary turret. By using the drilling attachment an independent speed may be given to the drill through the overhead gearing shown, and thus forming and drilling be performed at the same time

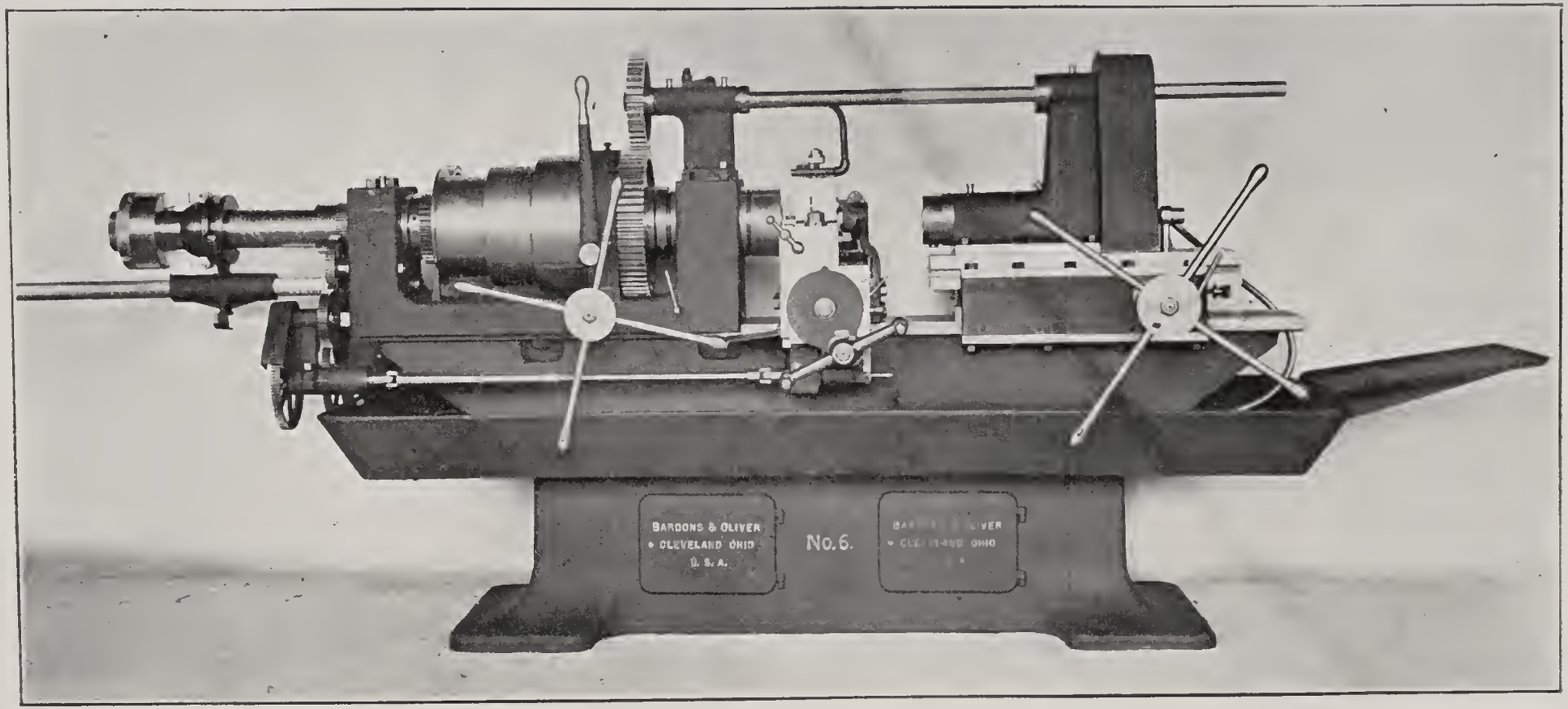

FIG. 51.

HEAVY FORMING MACHINE.

Bardons and Oliver, Cleveland, Ohio.

and at the best speed for each. This machine is intended primarily for bicycle and automobile hubs and hollow steel work of a similar character.

64. Automatic Screw Machine.

The machines so far noticed have been partially automatic, but such as to require the attendance and attention of the operator.

For the production of large numbers of small parts cut directly from the bar it is desirable to have a machine which is entirely automatic; which will take a bar of steel and cut it up into finished pieces, only stopping when that particular bar is entirely used, thus making it possible for one operator to attend several machines.

The Cleveland automatic screw machine is of this character, and is so far differentiated from the ordinary lathe as to really belong to another class. This particular machine is intended for handling work up to $2\frac{3}{4}$ inches in diameter and $6\frac{3}{4}$ inches long, has six holes in the turret, and two tool-posts on the cross-slide. The head spindle is at the left of the bed, and is driven by gears from a reversing countershaft at the rear, so as to eliminate any belt pull on the main bearings. The pulleys on the countershaft are arranged somewhat as are those on a planing machine, so that the automatic shifting of the belt reverses the machine and gives a quick return for screw cutting.

If bar stock is used, the feed and chucking arrangements are automatic. If small castings or forgings are to be handled, a magazine can be attached which will handle the pieces and only needs to be kept filled.

The turret consists of a horizontal cylinder mounted eccentrically in heavy bearings at the right of the machine and bored with six holes for tools in the end. The locking circle is larger than the tool circle, giving rigidity to the tools. The return of the turret automatically revolves it

into a new position as soon as the tool is clear of the work by means of the cam on the spindle. The cross-slide is fitted for two circular cutting-off or forming tools and is also automatic.

In fact the machine, as its name implies, is entirely automatic in its character, and is therefore particularly useful for the indefinite production of small duplicate parts.

It is possible in this machine to have different feeds for the different tools in the turret when desired.

65. Automatic Chucking Machine.

A lathe, automatic in its character but adapted more particularly for chucking larger work, is shown in Fig. 52, the cut illustrating a machine which will swing pieces 17 inches in diameter over the ways, and will finish over the carriage pieces 10 inches in diameter and $5\frac{1}{2}$ inches long.

By means of the longer lever in front of the head the chuck may be operated on either outside or inside grip, without stopping the machine.

The spindle is driven either by gears or belts from an automatic countershaft at the rear in such a way that the reversing is performed automatically, and that a change from fast to slow speed or the reverse may also be effected by the machine itself. For instance, if a piece is to be drilled and then turned, the machine will change automatically from the high to the low speed as the tools change.

The ordinary turret slide is used, operated in this case by the cam drum shown underneath. A set of cams is furnished with each machine suitable for doing all ordinary work up to the capacity of the turret.

The lathe is usually furnished with a cross-slide (not shown in the cut) carrying two tool-posts and entirely automatic in its action. By properly arranging the tools it is possible on some work to have from five to eight cuts simultaneously; and as the machine is automatic in all its

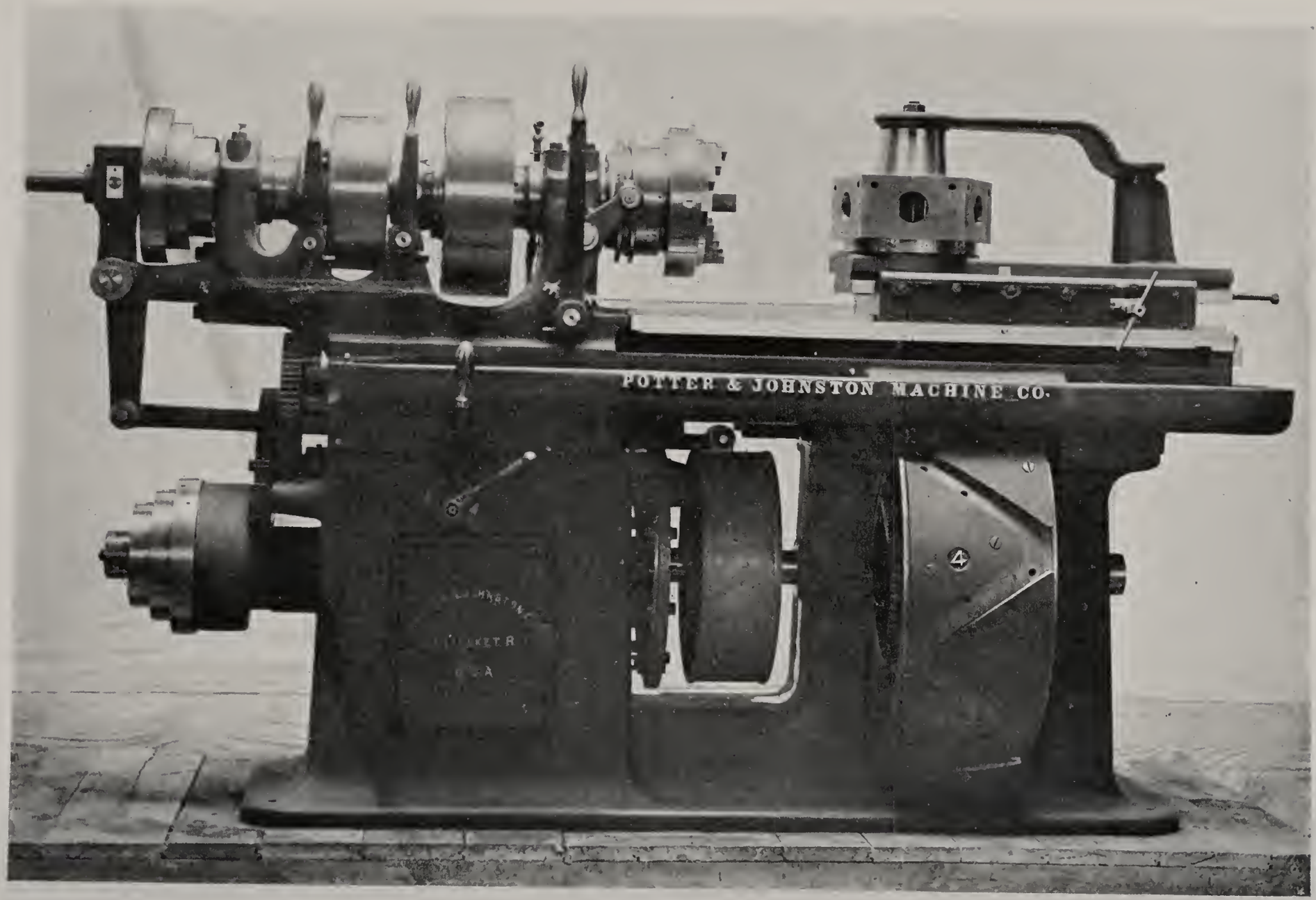

Fig. 52.

AUTOMATIC CHUCKING AND TURNING MACHINE.

cutting operations, one workman can attend to several machines.

The output of such a tool is, of course, far in excess of that of the engine lathe. As an example of its possibilities an instance may be cited where thirty clutch pulleys of cast iron 10 inches in diameter by 2-inch face were finished in ten hours, or an average of twenty minutes each. This included turning the rim, boring and facing the hub, and cutting a key-way.

66. Vertical Turret Machine.

The vertical machine bears about the same relation to the ordinary turret lathe that the vertical boring mill bears to the engine lathe. In fact, it is a small boring mill carrying a turret on the cross-rail.

The machine is intended for chucking castings and forgings, and possesses the usual advantages of vertical machines in the ease with which the work may be handled and inspected and in the rigidity of the chuck and spindle.

In the Warner and Swasey machine the main driving gear is cast to the spindle, and the line of centres of gear and spindle is directly under the line of travel of the cutting tool. There are three steps on the driving cone, two changes in the friction gearing operated by a lever, and two speeds to the countershaft, making twelve in all.

The turret is mounted much the same as the tool-post of a boring mill, the turret slide having a vertical movement on the saddle, the latter having horizontal travel on the cross-rail, and the rail a vertical adjustment on the housing. The saddle can also be swivelled through an angle of 30 degrees as on a planer or boring mill.

Both slides are fed by power when necessary, and each has eight changes of feed. Automatic stops are provided for tripping the feed at any desired point. All gearing is protected from dirt and chips by iron casings.

67. Power and Capacity.

Perhaps no other improvement of modern times has brought about a greater increase of output than the introduction of turret machinery. The multiplication of cutting edges in action at one time is one feature of the change, many of the lathes described being capable of performing several distinct operations at the same time. This characteristic is not peculiar to turret machines, but is common to drilling, boring, and planing machinery. The use of forming or shaving tools, which give a complete profile or outline at one cut, is another feature which has given the turret lathe an advantage over ordinary lathes. Add to the advantages above mentioned the automatic or semi-automatic action of most turret machinery, and you have a combination which has made it possible for this class of lathe to outstrip all competitors in quantity and quality of output. The fact that recent improvements in other classes of machinery along these same lines has enabled them in some cases to approximate to the production of the turret lathe is rather an argument for than against the lathe. Let it be remembered, however, that the advantages enumerated are dependent largely on the manufacture of large numbers of duplicate small parts, and that unless a company has reached the point where it builds its machines by fifties or by hundreds it will not get the full benefit of this method of manufacture. An increase of output cannot be obtained without a corresponding increase of power, since it requires just about so many horse-power to remove a hundred pounds of steel in an hour whether it is done by one tool or several. For this reason the turret machine is somewhat in the same class as the high-speed reduction lathe as regards power required to drive it.

Machines like those illustrated in Figs. 49, 50, and 51, with their wide pulleys and double gearing, may be expected to require about the same driving power as the lathes shown in Figs. 37 or 42.

Electric transmission has been employed to drive this type of machinery, but usually in groups rather than by independent motors. As the automatic machines for producing small steel parts directly from the bar are usually run in groups of from two to six machines attended by one operator, the circumstances are favourable for the use of one countershaft with friction clutches, driven by a single high-speed motor.

Some of the larger chucking and forming machines can be run, however, by independent motors, since from 2 to 5 horse-power is likely to be required for each lathe. The lathe shown in Fig. 50 can be equipped with a direct-geared motor located on the bed back of the headstock, a large gear being substituted for the cone pulley on the spindle.

CHAPTER V

BORING MILLS, VERTICAL AND HORIZONTAL

68. Vertical Boring and Turning Machinery.

In the last chapter reference was made to vertical turret machinery, and some of the advantages of that class of tools were mentioned. When pieces of considerable length of relatively small diameter are to be bored or turned, the superiority of the horizontal lathe cannot be disputed, the work being more easily handled and inspected when in this position. On the other hand, when castings or forgings of relatively large diameter are to be chucked and finished various difficulties present themselves.

The tailstock is now a superfluity, and the carriage and tool rest are no longer adapted to the work. There is difficulty in supporting the work while attaching it to the face plate, and when it is finally in place, the heavy mass of chuck and casting overhangs the bearings without adequate support and tends to cause springing and vibration. There is, moreover, difficulty in seeing the cutting tool on inside work, and the chips are continually in the way.

These various inconveniences have led to the more general adoption of the vertical type of machine, until at the present time the former method of chucking large work is rarely seen.

The advantages of the vertical boring and turning mill over the engine lathe for handling work of large diameter may then be summarised as follows :—Greater ease in placing

the work upon the machine and in supporting it while it is being clamped in position. Firmer support under the influence of its own weight and the pressure of the cutting tools. Better adaptation of the tool slides and supports for performing the required operations.

Boring mills may be classified according to the nature of the uprights or housings which carry the tool slides, thus :—1. Single-post machines such as that shown in Fig. 53, intended for relatively small work or for boring without turning. 2. Machines with two posts or housings used for both turning and boring, and ranging in size from 3 feet to 20 feet in diameter. 3. Machines with adjustable housings used for the very largest work, and frequently capable of swinging 30 feet in diameter.

69. Single-Post Machines.

The vertical turret machine described in Chapter IV. is an example of a boring and turning mill with but one housing.

Most machines of this class are equipped with a turret on the tool slide since they are intended for small work. If desired, the ordinary tool holder could be substituted without changing the design of the machine. Mills of this character are usually built to swing not more than 30 inches.

Fig. 53 shows a turret mill intended for boring alone, there being no cross-rail and consequently no horizontal movement for the tool. The machine is driven by a step cone without back gears, and the table is supported by a step bearing at the foot of the spindle and a journal bearing above. The turret has four holes fitted for shanks of drills or boring bars and has a vertical movement of 25 inches. The feed can be moved by hand, or by means of the worm and gear shown at the top of the mill. The general design of the frame is good, and the wheels and levers are conveniently arranged for the use of the operator.

70. Machines with Two Housings.

This is the standard type of vertical boring and turning

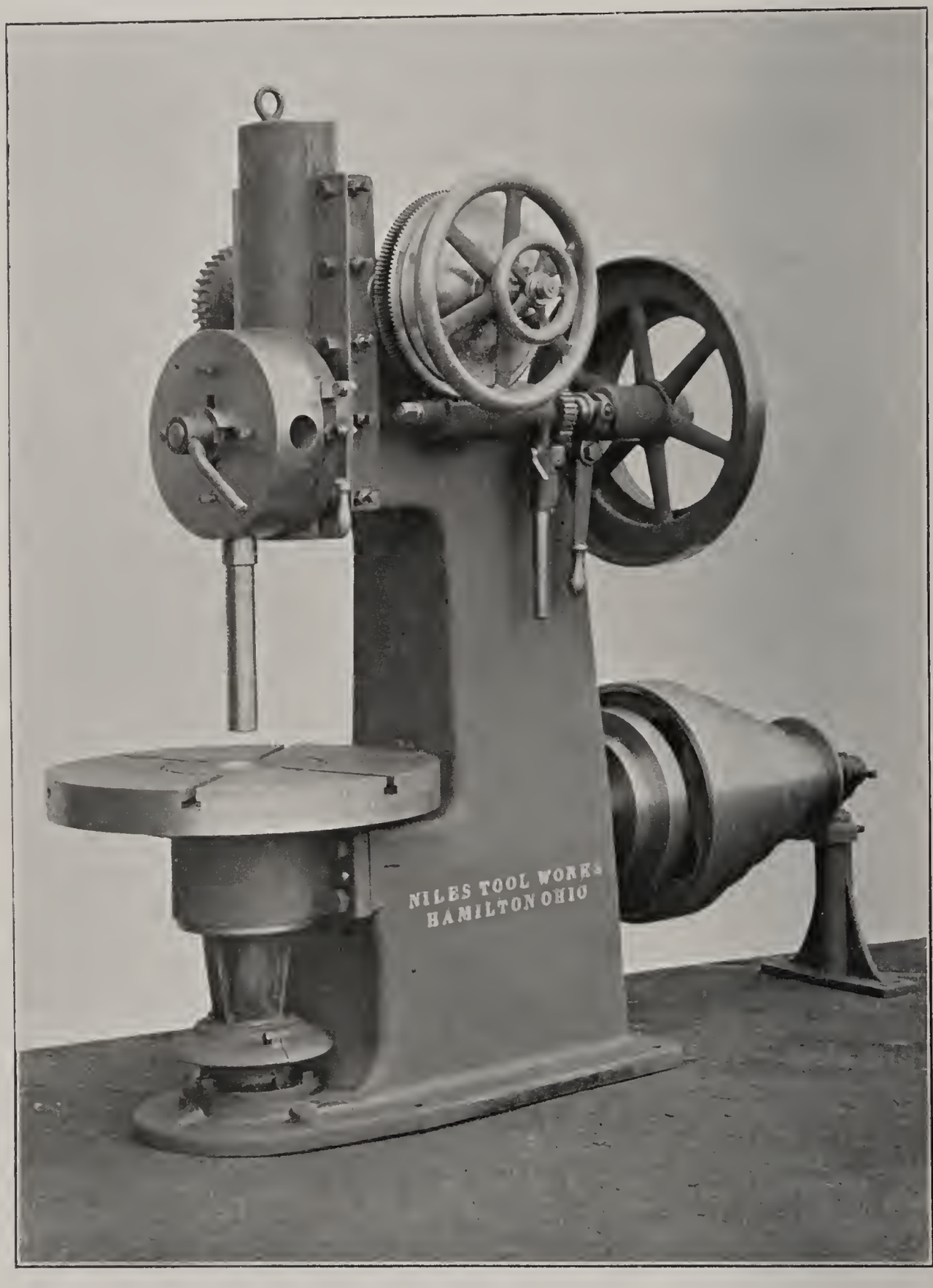

FIG. 53.

30-INCH TURRET BORING MILL.

Niles-Bement-Pond Co., New York.

mill, and as such merits a detailed description. Such a

machine consists of the following principal parts: (*a*) the revolving table and its supports; (*b*) the uprights or housings; (*c*) the cross-rail; (*d*) the tool-slide or head; (*e*) the driving mechanism; (*f*) the feed gearing.

As may be seen from the illustrations in this chapter, the boring mill resembles the planing machine rather than the lathe, and may be comprehensively described as a planer in which the table has a rotary instead of a sliding motion. This change in the cutting motion necessitates other modifications which will be attended to in the proper place.

71. The Table.

Like the spindle of a lathe, the table of a boring mill is the main feature in the design, for upon its accuracy depends the question of good or bad work. It should revolve easily and smoothly at high speeds, and should be rigid and steady under the wide cuts and heavy pressures incident to turning large work.

The spindles of relatively small machines such as that illustrated in Fig. 53 are sufficient in themselves for the support of the table, but care is taken that the driving pinion may engage the gear as nearly in line with the cutting tool as possible, to eliminate any torsion on the spindle itself. This same principle has been before noticed in connection with the direct gearing on large lathe chucks.

The tables of larger machines require additional support when used for turning large work, to prevent springing downward under the pressure of the tool.

For mills of moderate size the arrangement shown in Fig. 54 has been found accurate and durable and is peculiar to the make of mill indicated. The spindle proper has two cylindrical journals of different diameters, and an adjustable collar at the lower end to prevent any tendency to lifting of the table. Directly under the table is a larger conical bearing to take the vertical pressure.

In the 37-inch machine shown in the figure the maximum pressure on the conical bearing in the most extreme case

FIG. 54.

37-INCH TABLE AND SPINDLE.

The Bullard Machine Tool Co., Bridgeport, Conn.

would be only 46 pounds per square inch, while under ordinary circumstances the pressure would be much less than this.

The conical bearing has the further advantage of being

self-centering as it wears. Constant lubrication is effected through the stationary pipes shown in the cut. The table is driven by means of a small bevel pinion engaging a gear near its outer circumference. There is this disadvantage in the use of bevel gearing that it has a tendency to lift the table at the edge. The makers of the mill shown in Fig. 54 claim that this has been eliminated by the shape of tooth adapted.

The table of the machine shown in Fig. 55 is driven by a bevel gear on the outer edge. The vertical thrust is taken by hardened and ground-steel collars.

The 51-inch mill illustrated in Fig. 56 also has its table driven by bevel gearing. In this machine there are two annular bearings for the table, one near the outer edge and one close to the spindle. In all the machines shown in the figures the spindle is hollow to allow chips to fall through when boring is done.

In Fig. 57 no outer support for table is shown, and the vertical thrust is taken by a hardened steel step at the bottom which is submerged in oil. The driving mechanism consists of a bronze pinion on a vertical axis meshing with an annular gear just inside the rim of the table. This type of gearing seems to the writer the best for this purpose, since it does not tend to lift the table and will give a smoother motion under heavy cuts on account of the longer arc of contact between the teeth.

On some machines advantage is taken of the use of both a spindle step and a table bearing to make the former adjustable as to height. It is then possible, by raising the step, to relieve the pressure on the annular bearing under the table when running at high speeds on light work and thus reduce the moment of friction. The machine shown in Fig. 58 has this adjustment.

Worm gearing is used for driving the table on the 5 ft., 6 ft., and 7 ft. mills of the make illustrated in Fig. 59. It is well known that the action of worm gearing is smoother and

more continuous than that of spur or bevel gearing. For the high speeds used on the smaller machines this form of gear

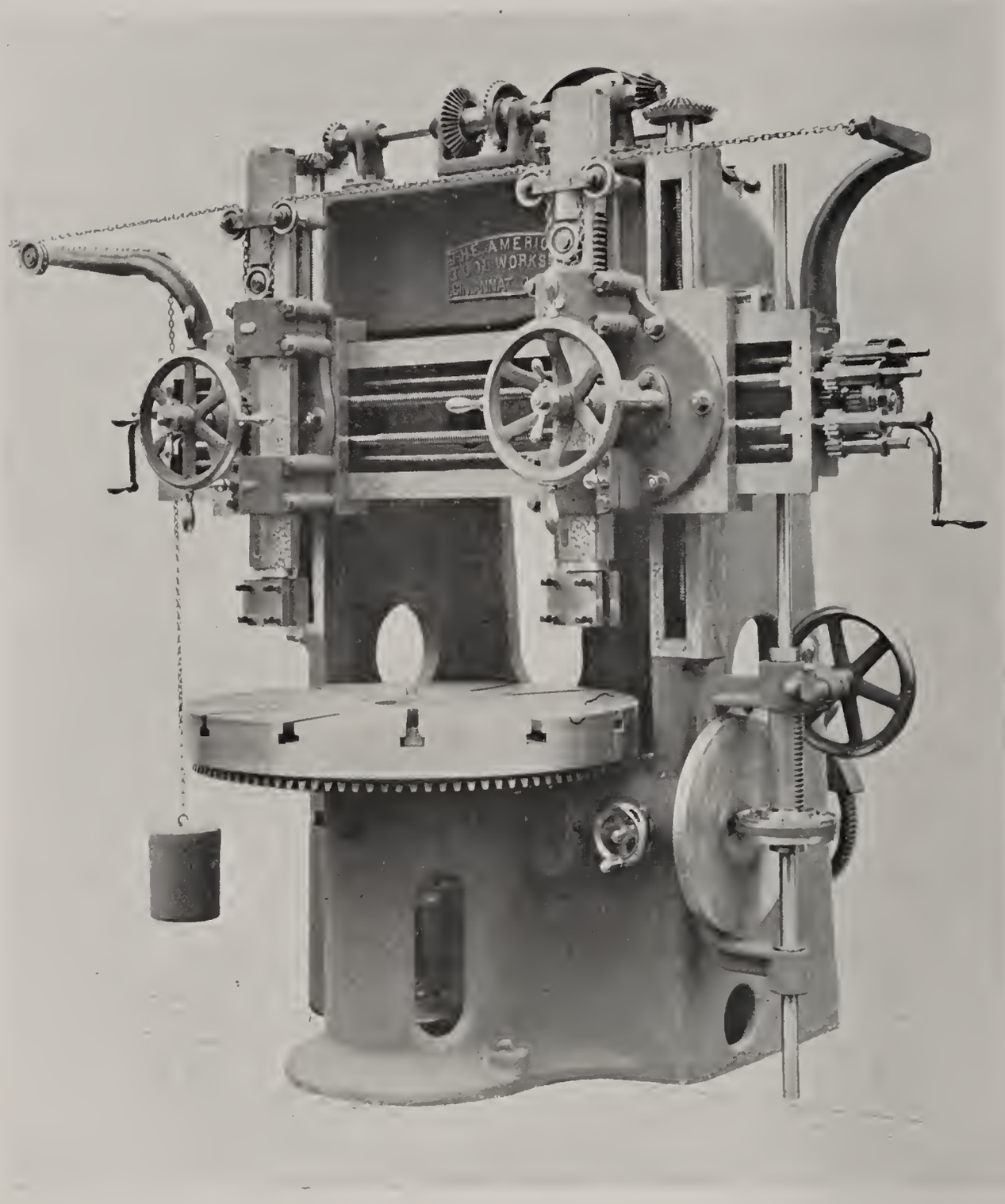

FIG. 55.

37-INCH BORING AND TURNING MILL.

The American Tool Works Co., Cincinnati, Ohio.

gives a smooth motion free from chattering. A ball-thrust bearing is used for the worm and the whole runs in a bath of oil. For larger machines and heavier work the worm gear is not available on account of its low efficiency and great end pressure.

The diameter of the table is usually slightly less than the rated swing of the mill and the vertical capacity under the rail from two-thirds to one-half the swing. The vertical movement of tool spindle is about two-thirds of the latter dimension. For instance, a 6-ft. mill would have a height of about 4 ft. under the rail and a vertical travel of tool of about 30 inches.

72. The Housings.

The uprights of boring mills are in many respects similar to those of planing machines, being usually parabolic in outline with flat front faces for the attachment of the cross-rail and connected together at the top by the top brace.

The severest strain which can come upon a housing is when turning work of large diameter and maximum height. There is then the full pressure of the cutting tool exerted at a point near the top of the upright just as when cutting large work in the planing machine. Side pressure of the tool also has the effect of springing the uprights to one side as in the planer.

In the smaller machines the housings and the bed are usually one casting, as in Fig. 55. In machines of larger swing the uprights are bolted to the bed, either to the top as in Fig. 57, or to cheeks on the side as shown in Figs. 56 and 59.

The latter would seem the better way as securing more rigidity. The location of the uprights is far enough back to bring the tools over the centre of the table, and the distance between them is usually several inches less than the diameter of the latter.

73. The Cross-Rail.

As may be seen by reference to the various illustrations in this chapter, the cross-rail has the same general characteristics as in the planing machines. It is gibbed to the flat ways on the uprights and is raised or lowered by power, a

counterpart on the top brace being geared to both elevating screws and being driven by belting from the driving shaft below. Fig. 56 shows this arrangement clearly. The rail

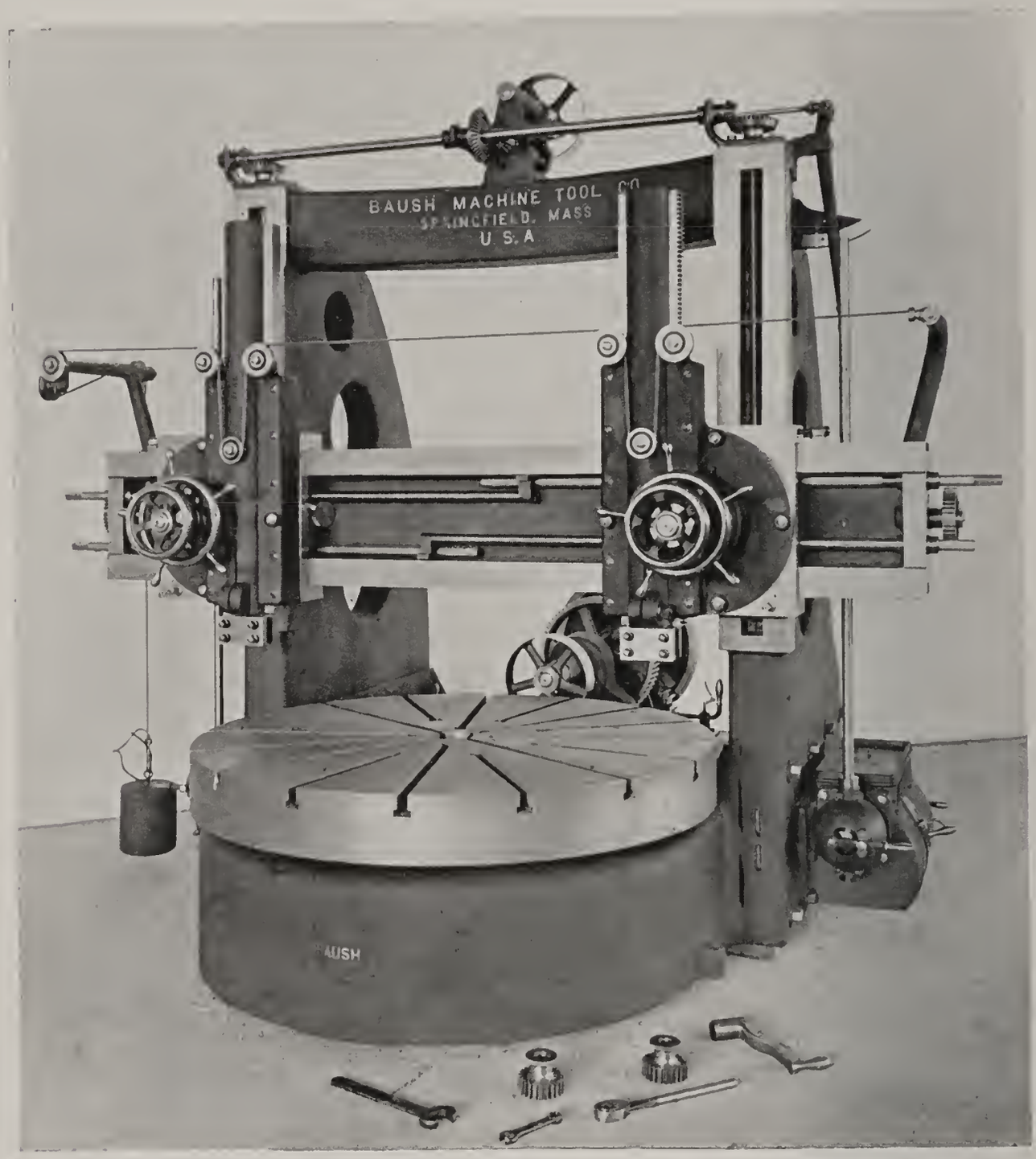

FIG. 56.

51-INCH BORING MILL.

The Baush Machine Tool Co., Springfield, Mass.

must have wide bearing surfaces for the tool saddles, and must be braced at the rear to resist bending. The usual form is that of a box girder. The top way of the rail must be rectangular to hold the overhang of the tool heads, while the lower one is sometimes bevelled as in Fig. 57.

74. The Tool Heads.

All boring mills of 37-inch swing and over have two heads, usually made right and left that they may be brought close together. The saddles are gibbed to the cross-rails and have means of adjustment for wear. The heads can be swivelled to any reasonable angle, and the rails are of such length that the tool can operate at the full diameter of the table when so swivelled.

The tool bar or head itself is of necessity entirely different from the corresponding member on a planing machine. The principal function of the tool head on a planer is to travel horizontally on the rail for wide surface cuts. In the boring mill, on the other hand, the turning and boring which constitute the greater parts of the work are done by vertical travel of the tool, while the horizontal motion is only used for facing.

It is therefore necessary that the tool bar should have ample bearing surfaces to resist wear, and that the bearings should have sufficient length to hold the tool firmly when it is at the lower end of its travel. A study of the various cuts will show how this has been accomplished. The bar itself is usually octagonal in cross section, with bearings on alternate sides, as shown in Figs. 55 and 57.

It may, however, be rectangular, as in Figs. 58 and 59, or cylindrical, as in Fig. 56, with wing slides. The material used must be steel of the best quality, combining great strength and stiffness with good wearing qualities.

In the machine shown in Fig. 55 two bearings are used, some distance apart, so as to resist the bending moment. These bearings are provided with caps to give compensation for wear.

The bearing is in most machines continuous, either with one cap covering the whole bar, as in Fig. 57, or with two gibs, one on each side, as shown in Fig. 56.

The vertical traverse is usually effected by a pinion

engaging a rack on the tool bar. In the best machines the rack is cut directly in the solid steel of the bar.

Nearly all the illustrations show a large wheel or turnstile on the tool head by which the hand traverse is effected,

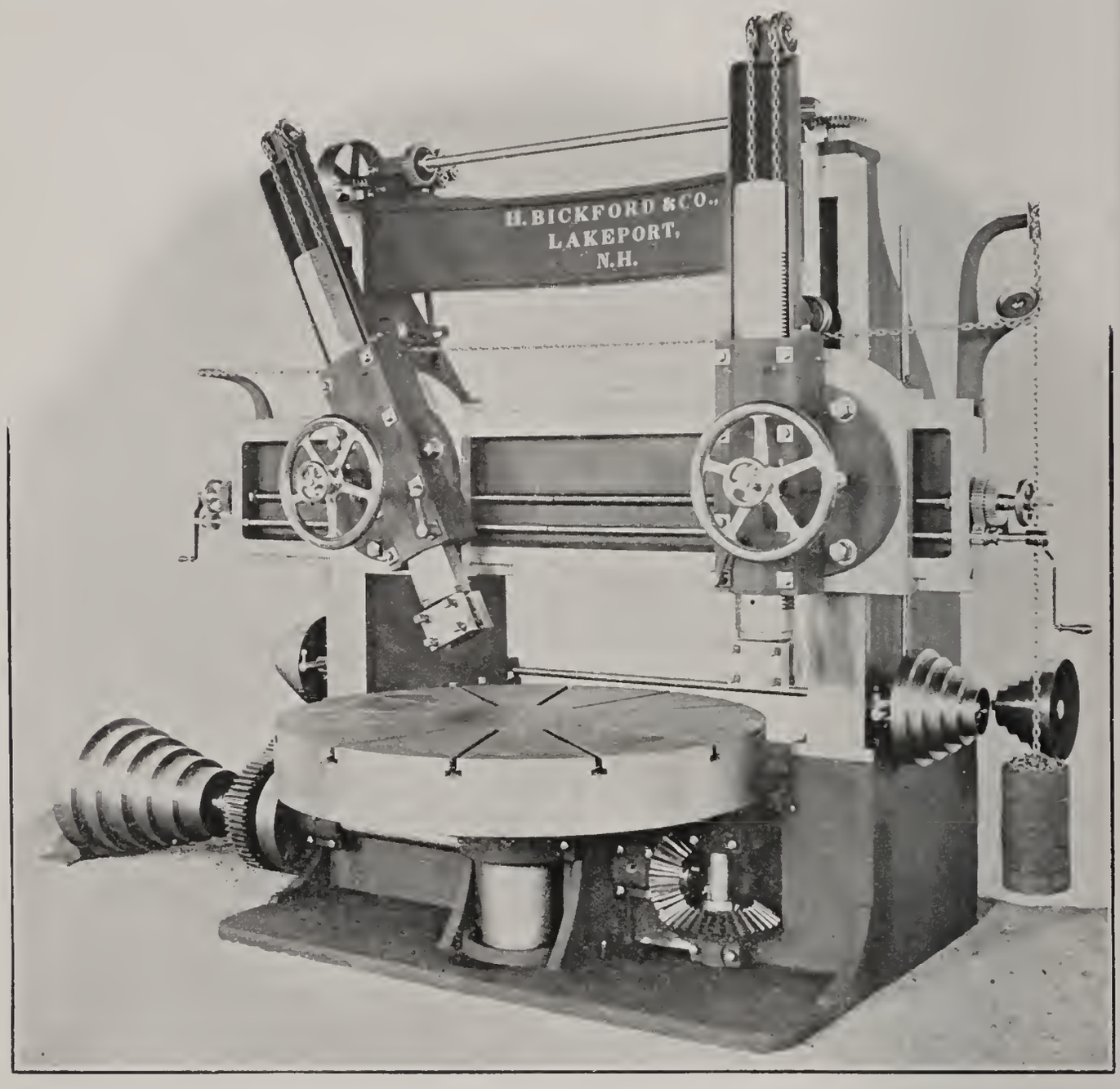

FIG. 57.

72-INCH BORING AND TURNING MILL.

H. Bickford and Co., Lakeport, N.H.

while the small wheel is used for throwing in the power feed. The great size and weight of the bars makes counterbalancing imperative. This is generally effected, as shown in Fig. 56, by carrying one rope or chain over and under guide pulleys in front of the tool heads in such a way as to counterbalance both with one weight. The objection to this particular

arrangement is the fact that the rope is sometimes in the way of the hoisting chain from the crane.

Fig. 57 shows how this difficulty has been met by keeping the chains back of the heads and cross-rail.

The feed rods and screws are so arranged that either head may be fed independently in any direction. The feed mechanism will be discussed in another paragraph.

Either head is usually so arranged that it may be run to the centre of the table and brought into exact alignment by a centre stop. One or both heads are fitted with a taper hole for receiving drill shanks, boring bars, etc.; and when in the centre position this hole is exactly in line with axis of table, so that a boring bar or reamer may be supported at its lower end.

It should be possible to clamp the tool slide at any required height when the machine is used for facing large work.

75. The Feed Mechanism.

In most boring mills the two heads have independent feeds, both horizontal and vertical, so that either may be used without any reference to what the other is doing. This is clearly shown in Fig. 56, where the machine has four independent rods, two for each head, driven from opposite ends of the cross-rail. In Fig. 55 the four rods are seen to extend entirely through the rail and to be driven by gearing on the right end. Reference to the various illustrations in this chapter will show that both these arrangements are common.

On the larger machines provision is made for throwing out the power feed, so that rapid traverse of the saddle on the rail may be effected by means of a rack and pinion motion, similar to that on the carriages of engine lathes. In fact, the manner of controlling the saddles and heads on this class of machine is so nearly identical with that used for operating the carriage and tool post of an engine lathe as to render detailed description unnecessary.

The feed gears on the end of the rail are driven by a vertical rod splined its whole length. It is in the driving of this rod that we find considerable variation among the several machines represented.

The mill illustrated in Fig. 56 has the Hendey-Norton system of gearing, the same as used on the lathes of that

Fig. 58.

10-FOOT BORING AND TURNING MILL.

Niles-Bement-Pond Co., New York.

name (see Fig. 30), and in this way gets fifteen changes of feed, either of which is instantly available. This makes it possible to do thread-cutting on the machine when desired.

The mill shown in Fig. 57 has cone pulleys and belts for making feed changes, while in the machine illustrated in Fig. 59 a slotted feed plate or crank is used for this purpose. A Bullard 42-inch boring mill is equipped with one turret head, and has its feed mechanism driven by two sets of gearing located on either side of the machine and entirely indepen-

dent of each other. Ten changes of feed can be obtained with this machine, the ratio of maximum to minimum being about 24 to 1.

On the other hand, the mills represented by the Figs. 55 and 58 have a friction-feed device. This is shown so clearly in Fig. 55 as to need little description. The advantages claimed for this device are ease of adjustment when the machine is in motion, and the possibility of finer variations. Some builders object to it on the ground that it is not powerful enough when the machine is taking heavy cuts, and that it does not give a sufficient range of feeds. It would seem to be particularly well adapted to light and rapid work, being more readily adjusted than the geared feed.

76. The Driving Mechanism.

As has already been noticed, the table may be driven by bevel, spur, or worm gearing, and this fact causes considerable variation in the general arrangement of the driving gear.

The first and last methods mentioned permit of direct connection between driving shaft and table, while the spur gearing necessitates the employment of an intermediate shaft as shown in Fig. 57.

The usual arrangement, especially for the larger mills, is to have the shaft at the side as in Figs. 57, 58, and 59, while in the smaller sizes the shaft is at the rear, as may be seen by reference to Figs. 55 and 56. The driving cone will have from four to seven steps depending upon the size of mill, and both double and triple gearing may be introduced. For instance, the 42-inch Bullard mill before mentioned has ten changes of speed, while the large 12-foot machine illustrated in Fig. 59 has thirty-six.

77. Electric Transmission.

The location of the driving shaft on a boring mill makes the application of electric motors particularly easy, and the fact that such mills are relatively large machines consuming

a considerable amount of power, points to the economy of independent motors.

The simplest and cheapest method of attaching the motor

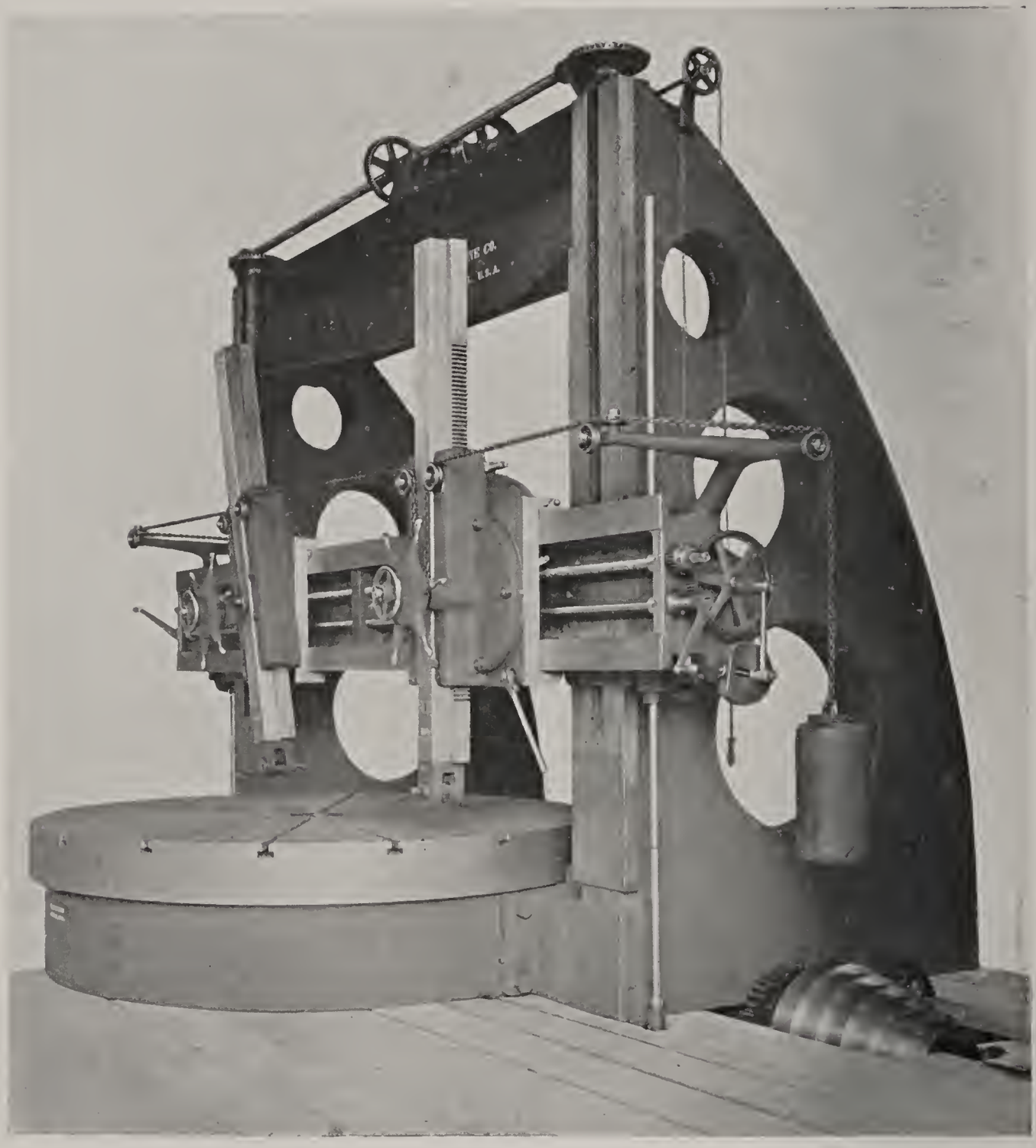

FIG. 59.

EXTRA HEAVY 12-FOOT BORING AND TURNING MILL.

Betts Machine Co., Wilmington, Del.

is probably that in which a constant-speed motor is belted to an overhead countershaft, and the ordinary mechanical speed control is not disturbed.

As in the applications which have already been noticed, the constant-speed motor has the advantage of simplicity and cheapness, since a small, high-speed unit may be employed. The desirability of electric speed control in operations involving gradual changes of speed has already been alluded to. Where shop space is limited the belted arrangement is objectionable.

Under these circumstances the variable-speed motor, such as shown in Fig. 60, offers a welcome solution. Such machines are compact and more readily controlled, but are necessarily rather more expensive. A silent chain drive may connect the motor with the driving shaft, so that electric control and double gearing together give the necessary speed changes.

In Fig. 60 a slow-speed motor connects directly with the shaft, taking the place of the usual cone pulley without modifying the general design of the machine in the least.

78. Power and Capacity.

The boring mill, from the nature of its work and the conditions which brought it into existence, is a heavy-weight machine and a large consumer of power. Such machines as have been illustrated in this chapter weigh from 5000 to 75,000 pounds, according to size, the former figure corresponding to the 30-inch and the latter to the heavy 12-foot machine.

The power required in proportion to the amount of metal removed per hour is somewhat greater than for a lathe of the same swing. Experiments made under the direction of the writer at the shops of the Wellman-Seaver-Morgan Co. in Cleveland were reported in *Cassier's Magazine* for December 1903, from which the following results are taken. A test on a 37-inch boring mill driven by a direct-connected, variable-speed motor of five horse-power developed the results given in the following table.

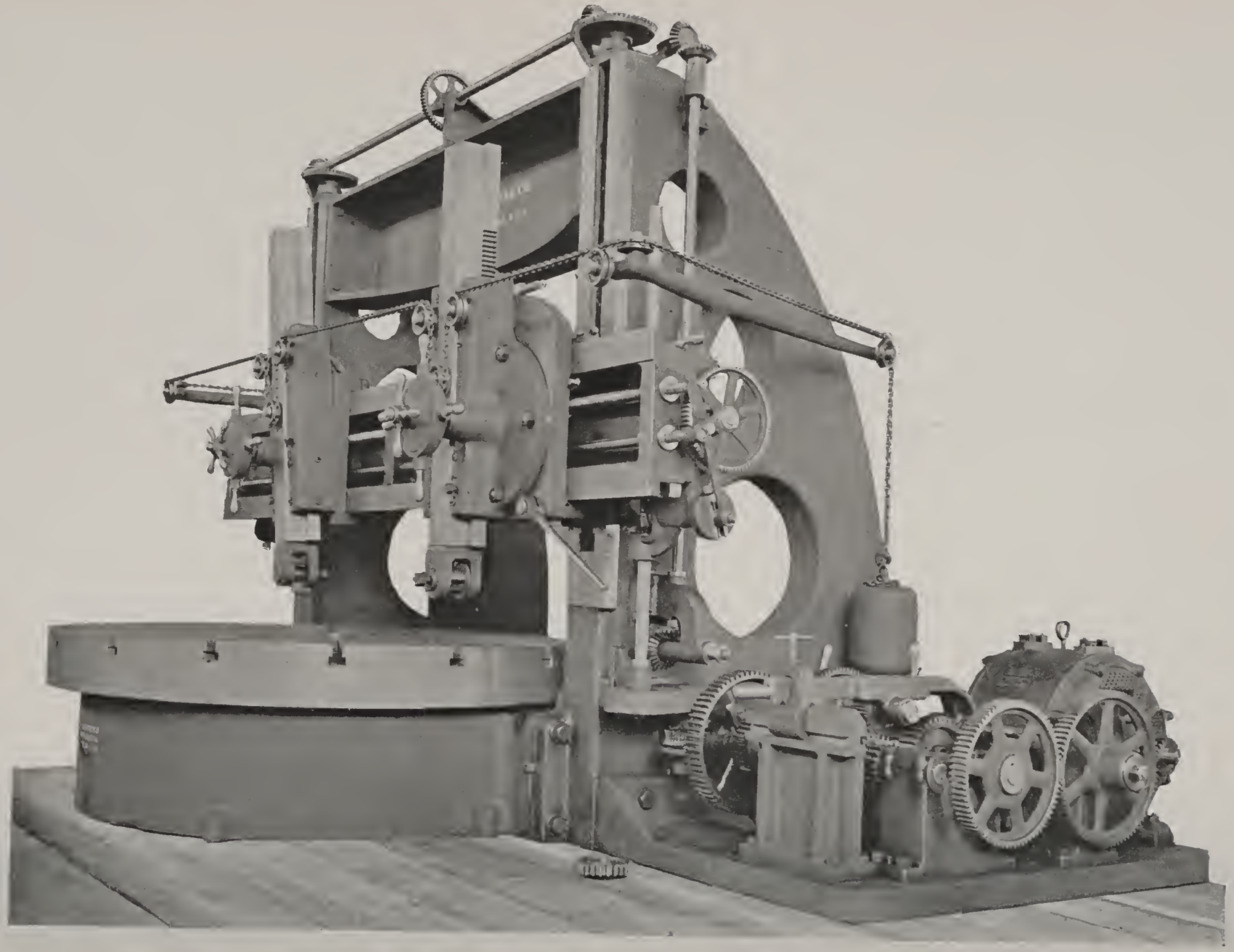

FIG. 60.

GEARED ELECTRIC DRIVE FOR BORING MILL.

Betts Machine C[illegible] Wilmington, Del.

Work, cast steel gear blank, $22\frac{1}{2}$ inches in diameter and 5 inches face.

Cutting Metal.			Running Idle.
Controller Notch.	Time. Minutes.	Horse-Power.	Horse-Power.
5	33	3·00	1·36
6	52	3·21	1·31
7	5	2·16	1·31
9	10	2·12	1·57

Total duration of test, . . . 1 hour 40 minutes.
Total weight of metal removed, . 31 pounds.
Metal removed per net H.P. per hour, 17·8 pounds.
Net H.P. per pound of metal per hour, 0·056.

Similar tests on five different machines, ranging in size from 3 to 10 ft. swing, showed a consumption of power when running empty of from one to two horse-power, and an average net horse-power consumed in cutting metal of ·091 per pound of metal per hour. Two lathes of 4 ft. and 5 ft. swing in the same shop required from one to two horse-power empty, but only consumed from ·045 to ·07 horse-power per pound of metal per hour, the first figure being for cast iron and the latter for cast steel. The motors used on the lathes were of the same character and size as those used on the 5 ft. and 8 ft. mills respectively.

The table below shows common practice in the matter of motor power for boring mills, the motor in each case being supposed to be amply large for any probable over-load on the machine.

Swing.	Horse-Power of Motor.
10 feet	10 to 15
8 ,,	7·5 to 10
7 ,,	7·5 to 10
6 ,,	5 to 7·5
5 ,,	5 to 7·5
4 ,,	5
3 ,,	5

The variations in power for the same size of machine are due to a difference in the character of the work and in the material to be cut.

Although the power required in proportion to material removed is probably greater than for an engine lathe of the same capacity, the greater convenience of the boring mill, and the rapidity with which work can be handled and machined, are advantages which outweigh all other considerations. When worked to its limit, the boring mill can undoubtedly remove more metal per hour than a face-plate lathe of the same swing.

79. Mills with Movable Housings.

When most of the work handled in a shop is of a certain standard size, and there are only occasional pieces of a larger diameter, it is convenient to have a machine which can be temporarily extended for the larger work. This general question has already been discussed under the head of gap lathes and widened planers, and nothing further need be said here.

In a machine of this class the housings are arranged to slide on grooved ways to and from the table, and can be firmly bolted in the desired position.

In all large machines it is necessary that this adjustment should be effected by power. To allow of boring when the housings are drawn back, an extension head is attached to the cross-rail.

In some machines this extension takes the shape of an auxiliary cross-rail at right angles to the main rail, and fitted with a saddle and tool head of its own. This construction permits of the use of the auxiliary for boring, turning, and facing the casting on the hub while the other heads are working at the larger diameters.

80. Horizontal Boring Machines.

As the boring mills just considered take the place of the lathe with the work bolted to the face-plate, so the hori-

zontal boring machine has been designed as a substitute for the lathe with the work bolted to the carriage. In finishing either plane or cylindrical surfaces, there constantly arises the question as to whether the work or the tool should move for the cut, and as to whether the work or the tool should traverse for the feed. Planer versus shaper is one example of this, and boring in the chuck versus boring on the carriage another.

The proper method depends upon the shape and size of the piece, and the shape and surface of the cut. An intelligent workman would mount cylindrical pieces of large diameter and slight overhang upon the face-plate of his lathe, especially if the surface to be finished had the same characteristics. On the other hand, if the part to be machined was irregular in shape and the finish consisted of holes of small diameter and considerable depth, he would bolt the work to the carriage and use a boring bar.

Precisely the same considerations would determine his choice of vertical mill or horizontal machine. In other words, it is primarily a question of holding the cutting tool. Wheels, pulleys, rings, and short cylinders are best handled on the vertical boring mill. Frames, headstocks, brackets, and long cylinders naturally find a place on the horizontal machine. The latter machine has been evolved from the engine lathe by a gradual process of selection and growth. The carriage of the lathe was never well adapted for carrying work, since it had no vertical or horizontal adjustment, and to get the work in line required a tedious process of blocking.

Furthermore, the spindle of the lathe had no traverse for feeding the boring bar or reamer, and it was necessary to move the work against the tool at a sacrifice of power and convenience.

We may then briefly define a horizontal boring machine as a lathe in which the spindle has a longitudinal traverse, and the carriage has one or more adjustments for setting the work.

As a study of the following pages will show, there is considerable similarity between the various types of machine, the principal difference being in the method of adjustment of the table to the spindle, and *vice versa*.

Perhaps the best way to classify the different machines would be as follows: (1) Machines with stationary heads and universally adjustable tables. (2) Machines with adjustable heads. (3) Duplex or multiple spindle machines. (4) Special machines for a limited range of work.

81. Machines with Stationary Heads.

This, the usual type of machine, is that illustrated in Fig. 61, which shows the ordinary characteristics of the type. An analysis reveals the following elements, which may be discussed separately :—

(*a*) The frame and housings or uprights.
(*b*) The head and its boring spindle.
(*c*) The table and its supports.
(*d*) The feed and speed control.

82. The Frame.

The frame of the usual type of boring machine consists of a flat bed-plate resting on the floor as on a foundation and having a flat top planed true and furnished with T-slots. In extreme cases it would be possible to remove the table and mount the work directly upon the bed-plate.

On one end of this bed is bolted the cabinet for the head-stock. On the other end is clamped the adjustable housing or yoke which forms a characteristic feature of this type of machine. The primary use of the yoke is to hold a bushing for the outer end of the boring bar; but aside from this it serves to steady the outer end of the table, the slides of the yoke being slotted to receive clamping screws. The yoke can be adjusted to and from the head for different lengths of bar,

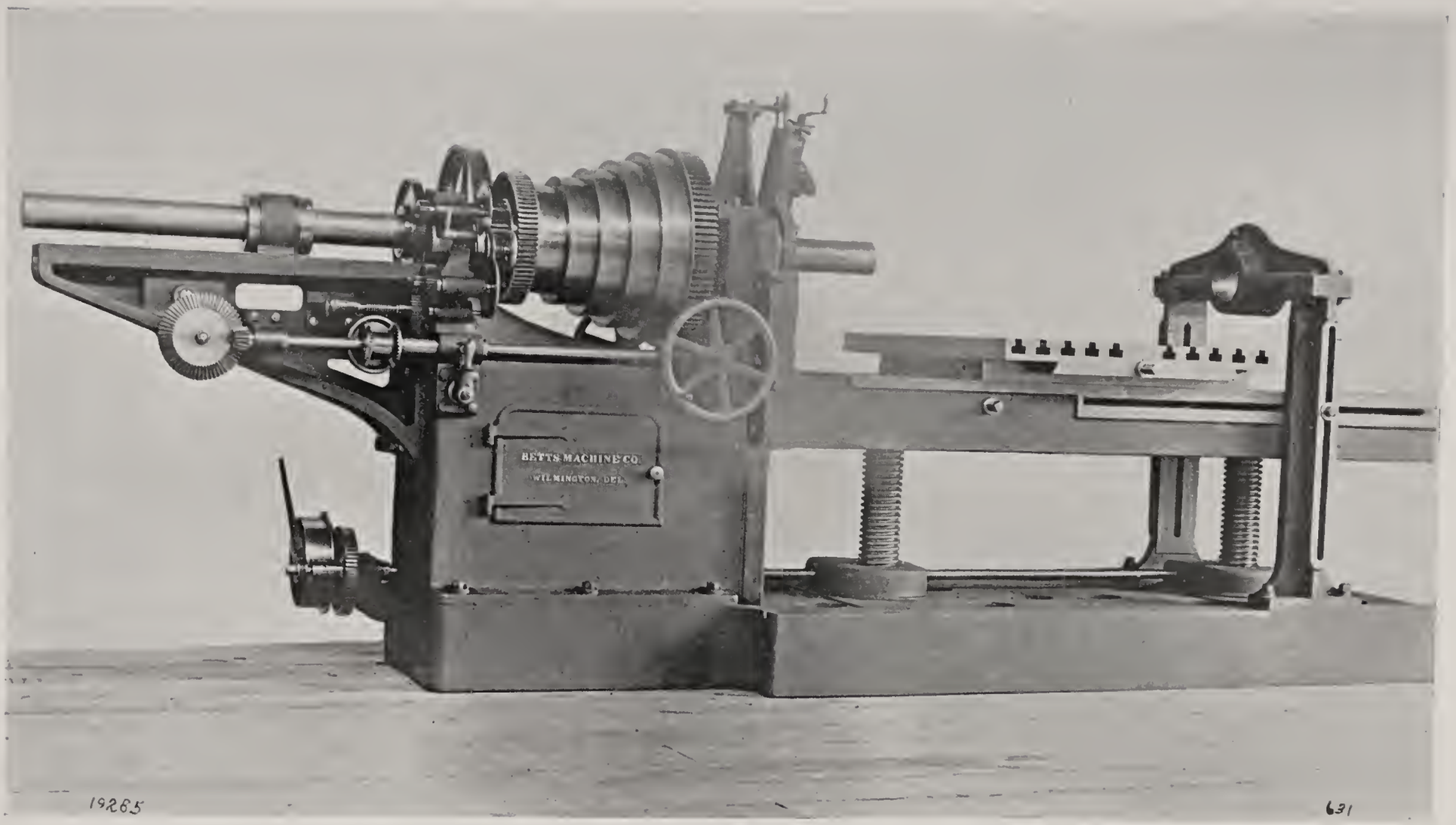

Fig. 61.

HORIZONTAL BORING AND DRILLING MACHINE.

Betts Machine Co., Wilmington, Del.

and on the larger machine screws and crank are provided for moving it. The cabinet is usually in one casting with the headstock, and has on the left side a long bracket to support the mechanism for feeding the spindle.

The general design of machines of this class shown in Fig. 61 is pleasing to the eye and in accordance with modern ideas on this subject. The machines are well balanced and free from useless curves and ornamentation.

83. The Boring Head.

The stationary headstock of machines such as that in Fig. 61 differs little from that of an engine lathe save in the provision made for longitudinal motion of the spindle. The last-named piece is of steel and has both a rotary and a sliding motion. Outside it is another spindle, usually of cast iron, which has only the rotary motion in the spindle bearings and which turns the steel spindle by means of a key or feather. The feed or traverse of the inner spindle is effected by a sleeve between two collars seen in the cuts at the left of the headstock. This sleeve slides to and fro on the long bracket and is controlled by a rack and pinion mechanism.

The machine illustrated has the usual arrangement of cone pulley and back gears. There are five steps on the cone and double back gears, giving fifteen spindle speeds in all. Some machines have a triple-geared drive, the cone pulley being on a separate shaft, an arrangement which has already been noticed in some turret lathes.

The advantages of this combination are the absence of any belt pull on the spindle bearings and the possibility of taking off the cone belt at any angle.

By means of a lever near the main driving gear the machine can be stopped or can be started with either a fast or a slow motion. The boring bar itself is provided with the usual slots for the insertion of cutters and with a taper hole in the end for the accommodation of drills and reamers.

A face plate on the outer revolving spindle may be arranged to carry a facing head with automatic feed as shown in Fig. 61.

It will be noticed that in the spindle arrangement of the machine just described the steel spindle is not subject to any journal wear since it has only a sliding motion in the outer spindle. The journal bearing comes on the outer spindle alone which revolves in the usual head boxes.

84. The Table.

The table is somewhat similar in character to that of a milling machine, a sliding bracket supported by screws. It is gibbed to vertical ways on the head cabinet and is raised and lowered by vertical screws. The smaller machines have one and the larger two of these screws. They turn by power, usually by means of worm wheels engaging with endless screws on a horizontal shaft.

This shaft, as may be seen in the cut, is driven by a pulley and disengaging clutch at the left of the machine. The table may be clamped at either end when in position. A saddle capable of being moved lengthwise of the table and fastened in any desired position carries in turn the carriage itself. The latter can be adjusted cross-wise of the table and is provided with the usual T-slots for fastening the work. It is thus possible to clamp work rigidly to the carriage without the use of blocking, and then by a combination of the vertical and two horizontal adjustments to bring the work into the desired relation to the boring spindle.

85. Speed and Feed Mechanism.

The speed changes have already been alluded to, being similar in character to those of an engine lathe. There are from eight to fifteen different speeds, depending upon the size of the machine.

The feed mechanism is confined entirely to the longitudinal movement of the spindle as the adjustments of the table are controlled by hand.

In both machines illustrated there is a quick feed operated by the hand-wheel in front of the headstock. Six or more automatic feeds are furnished and provision is made for reversing the feed without reversing the machine itself. The motion of the spindle is effected by a rack attached to the sliding sleeve before mentioned.

On some special machines a power cross-feed is provided for the carriage, and also a rotary table with circular feed. These attachments make it possible to use the machine for straight and circular milling, and really have nothing to do with the boring functions of the machine.

86. Capacity and Weight.

The class of machines just described have tables not to exceed 10 feet in length and at a maximum distance from the spindle of not more than 3 feet. The usual range and weight may be determined from the following table :—

Length of Table. Feet.	Centre to Carriage. Inches.	Feed of Spindle. Inches.	Carriage Cross Feed. Inches.	Net Weight. Pounds.
4	20	18	16	6,000
6	25	30	24	10,000
8	30	36	30	16,000
10	35	36	30	30,000

87. Machines with Sliding Head.

There are certain disadvantages in making the table of a boring machine adjustable vertically which have led to the adoption of a different type by some builders. The raising and lowering of the table is attended with some difficulty

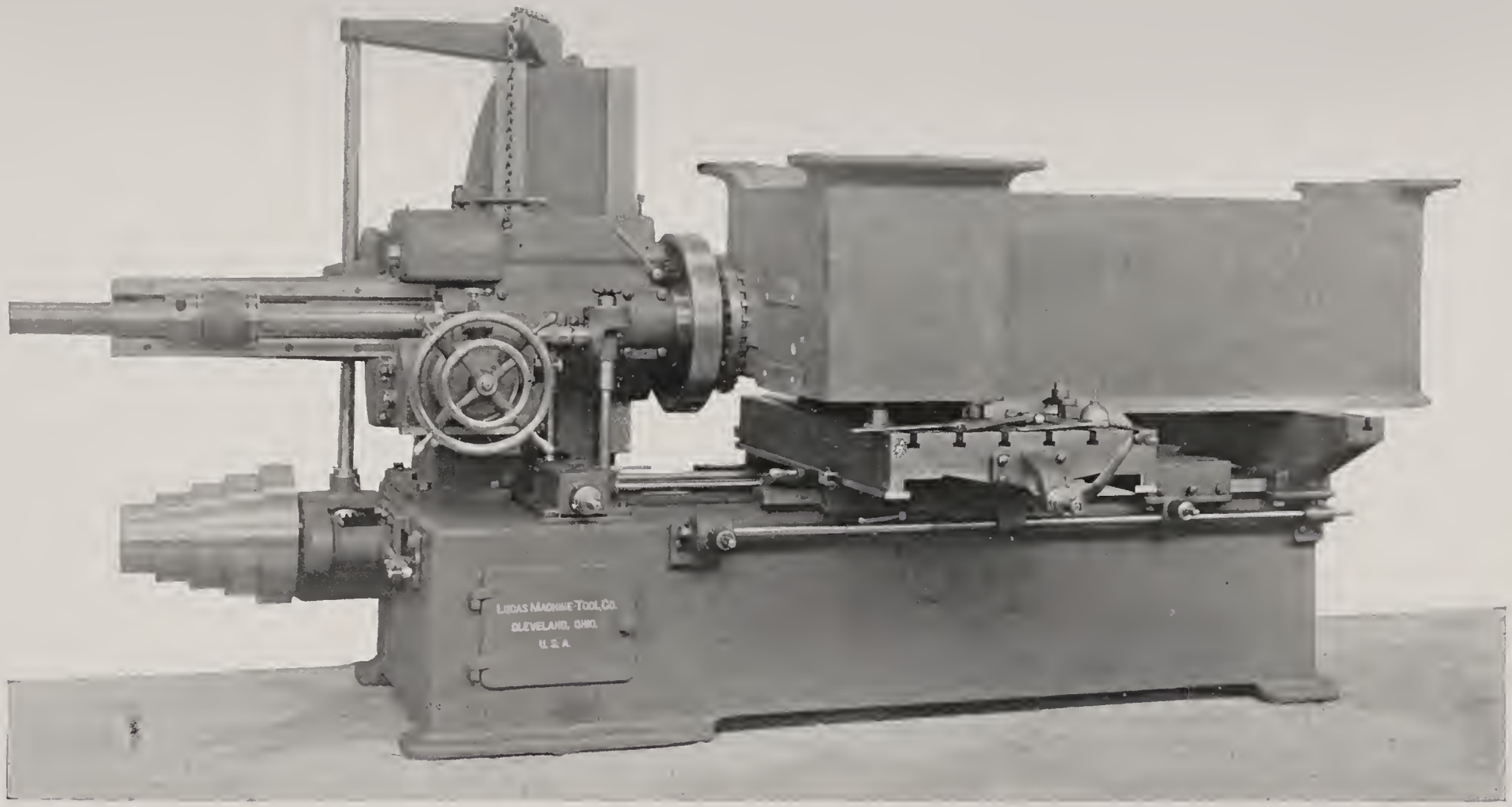

FIG. 62.

HORIZONTAL BORING MACHINE.

Lucas Machine Tool Co., Cleveland, Ohio.

when the work is unusually large or heavy, and the necessary length of table in the larger machines renders it difficult to secure the proper firmness and rigidity.

In Fig. 62 is shown a machine with the vertical adjustment in the head itself. The weight of the head and its attachments being practically constant, it is possible to so counterbalance them as to make adjustment easy.

The bed in this case takes the form of a box girder similar to a lathe bed, and the carriage or saddle rides directly upon this. The yoke for the outer end of bar is fastened to the same ways. The advantages of this arrangement for some kinds of work are well shown in the illustration, where the heavy bed of another machine is shown mounted and ready for boring and facing. The impracticability of doing a job of this size on the ordinary machine is evident.

The machine shown is provided with milling feeds for both spindle and platen, so that facing of plane surfaces may be done without resetting the work. When the head is used for boring, the head itself and the bushing in the yoke which supports the outer end of bar are raised or lowered simultaneously by means of a connecting shaft. As is clearly shown in the figure, the head slides on a vertical housing, being counterbalanced by a chain and weight, and can be clamped in any desired position. The necessity for a vertical adjustment of the head complicates the driving mechanism somewhat.

The power is transmitted from the driving cone by means of bevel gears and vertical shafts and is thus available for the rotating of the spindle, the feed of the boring bar, the elevation of the head, and the longitudinal and transverse feeds of the carriage. The face plate on the end of the revolving spindle is driven by a pinion and annular gear. Facing attachments may be bolted directly to this plate and thus be used independently of the boring bar.

The makers call this a precision machine from the fact that all adjusting parts are cut with special care, and that

the use of micrometers permits the machine to be set accurately without the use of jigs.

88. Large Machines.

As the size of machine increases the weight of table and work forbids any attempt at adjustment there, and all the vertical and horizontal motions are given to the head of the machine. Fig. 63 gives a good idea of this type, and represents a machine having a vertical adjustment of 4 feet and a horizontal travel of 8 feet, with a 3-foot traverse to the boring spindle. The bed of such a machine consists of two parts, the large stationary floor plate and the parallel ways for the travel of the column. The ways are usually flat, and the foot of the column has gibbed slides of large area. The extension shown in the cut forms a platform for the operator.

As may be seen in the figure, the driving mechanism is all located at one end of the ways, there being the usual cone pulley and back gears for the main drive, and in addition gearing for moving the column on the ways and for hoisting the saddle on the column.

As it is especially desirable on such large machines that the work should be finished with as little resetting as possible, feeds suitable for milling and facing are given to both column and saddle. After once setting the work on the table it is then possible to bore all parallel holes and to face all flat surfaces within reach.

The saddle is counterweighted and moves on broad, flat ways. The face-plate on the spindle has teeth cut on its edge and is directly driven by a cut pinion.

Quick traverses as well as power feeds are provided for all the adjustments, and the controlling levers and handles are all within easy reach of the operator's platform. From this one position he can control the speed of boring, can raise or lower the saddle, or can move the column either way. Some

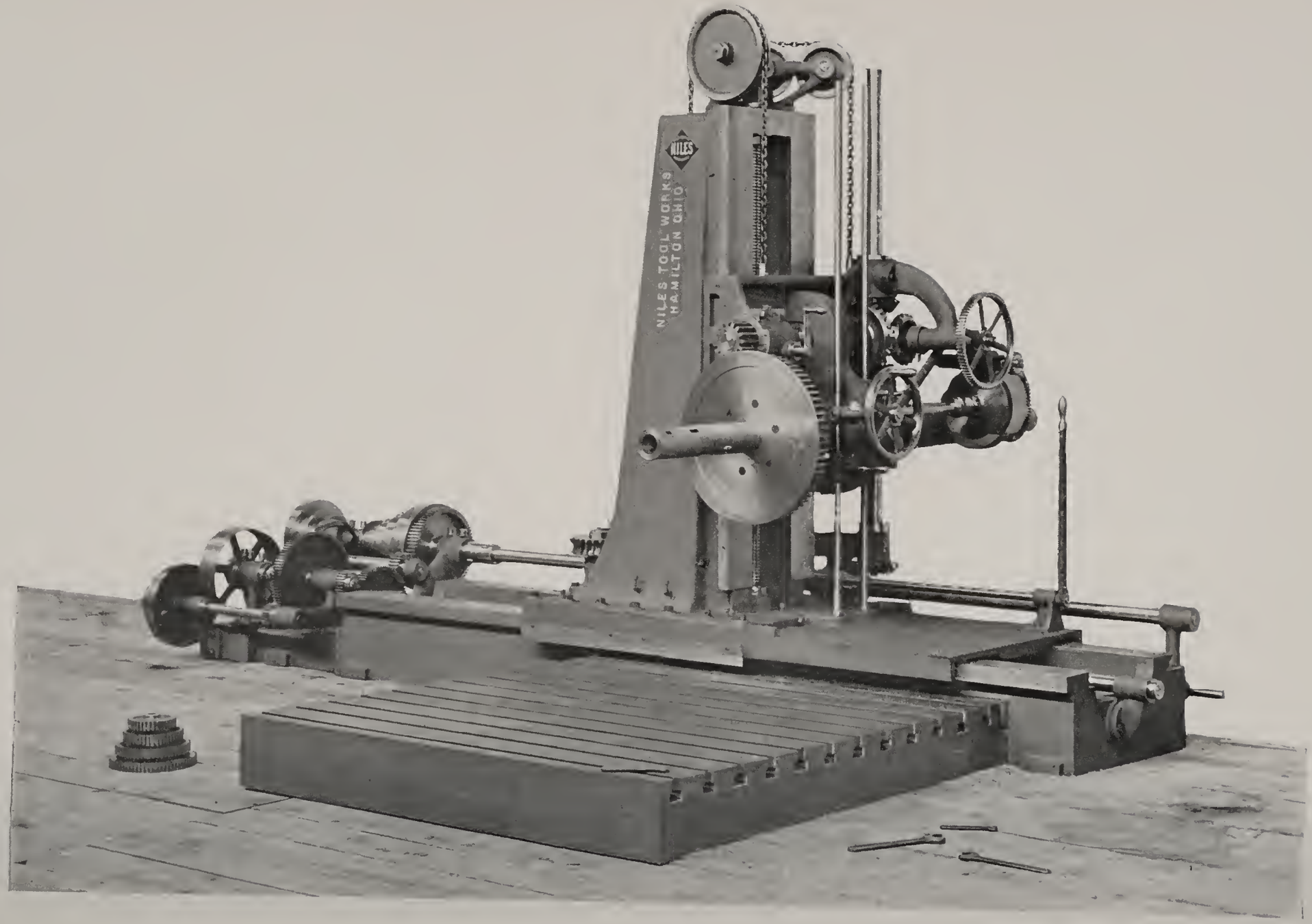

Fig. 63.

HORIZONTAL BORING, DRILLING, AND MILLING MACHINE.

machines are provided with tapping attachments by which holes may be drilled and tapped without resetting the machine.

In finishing beds and frames of unusual weight and size, it is practicable to move a machine of this character to the work and perform all necessary operations without disturbing the piece operated on.

If an outboard bearing is needed for the boring bar, a column is bolted to the floor plate for this purpose.

89. Tilting Table.

Fig. 64 illustrates a so-called universal machine for drilling and boring holes at any angle. The bed and column of this machine are similar to those just described, but in place of the usual floor plate is substituted an adjustable table.

This table has a horizontal motion to and from the column, a rotating motion on a vertical axis, and a tipping motion from 0 to 90 degrees. To quote the language of the makers, 'it is possible on this machine to drill and face holes on five sides of a cube without re-chucking.'

The adjustments of the table are made by means of worms and gears operated by hand cranks, as they are not intended for feed motions. The head of the machine has the feeds usual in machines of this class. The advantages of this type of table are too apparent to need discussion. The machine as shown is driven by an electric motor with geared speed control.

90. Cylinder-Boring Machines.

Among special machines may be numbered those intended for boring the cylinders of pumps and engines. The cylinders of the duplex pump frequently being in one casting are best finished on a two-spindle machine, which will bore both cylinders at once. This machine is fashioned on the engine lathe plan with a stationary head and an adjustable

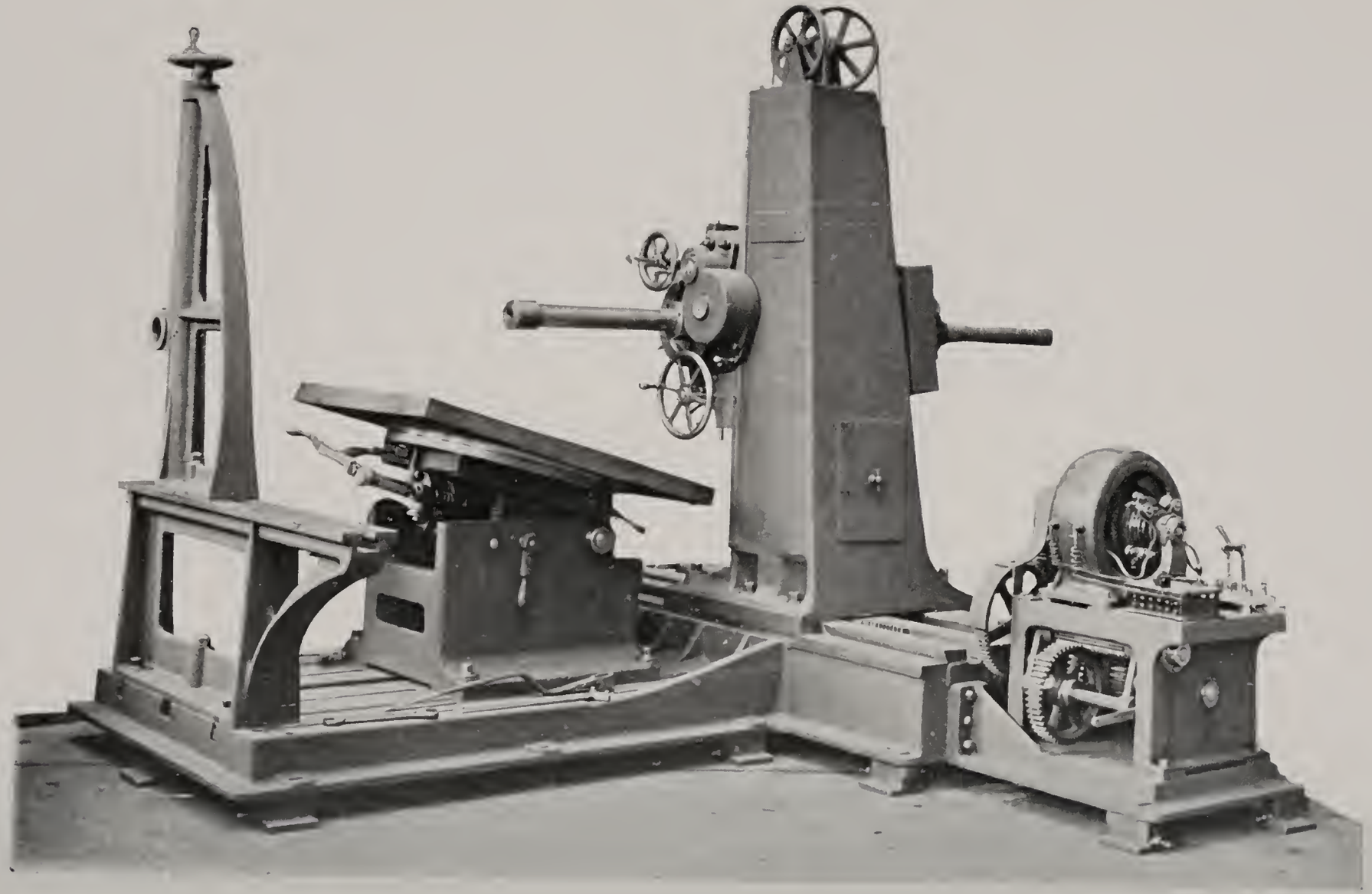

FIG. 64.

40-INCH MACHINE, WITH UNIVERSAL TABLE MOTOR-DRIVEN.

Detrich and Harvey Machine Co., Baltimore, Ohio.

carriage travelling on ways. The two spindles are precisely alike, and the outer ends of the boring bars are supported by a double yoke fastened either to the carriage or to the bed.

Fig. 65 illustrates a characteristic design for this type of machine. The great strength and rigidity of construction are manifest from the illustration and show the capabilities of the machine for heavy and continuous work.

The extensive use of the Corliss type of engine with its cylindrical valves at right angles to the cylinder proper, has led to the design by the Niles Tool Co. of a machine especially adapted for boring cylinders and valve ports simultaneously. As would be expected in a machine for such heavy work, massiveness is the prevailing characteristic. The boring bar has itself a hand traverse for setting, but the feed for cutting is accomplished by sliding the boring head along the bar, a feed screw being used for this purpose. The economy of room by this modification is apparent. The bar is of large diameter and supported at each end by long bearings. The feed of the cutter head is regulated by change gears at the head end. There are two facing heads clamped to sleeves which revolve with the bar, and which can be swung down out of the way when not in use.

The peculiarity of this machine, however, is in the two auxiliary columns which carry the bars for boring the ports. These really constitute an independent boring machine at right angles to the main machine and equipped with two adjustable heads. These heads have the usual boring and facing attachments, and are driven independently of the main machine by a cone pulley.

It is thus possible to conduct the port-boring without reference to the other work, since the setting of the cylinder is undisturbed.

Such a machine is not adapted nor intended for miscellaneous work, but finds an ever-widening field as the manufacture of large Corliss units increases.

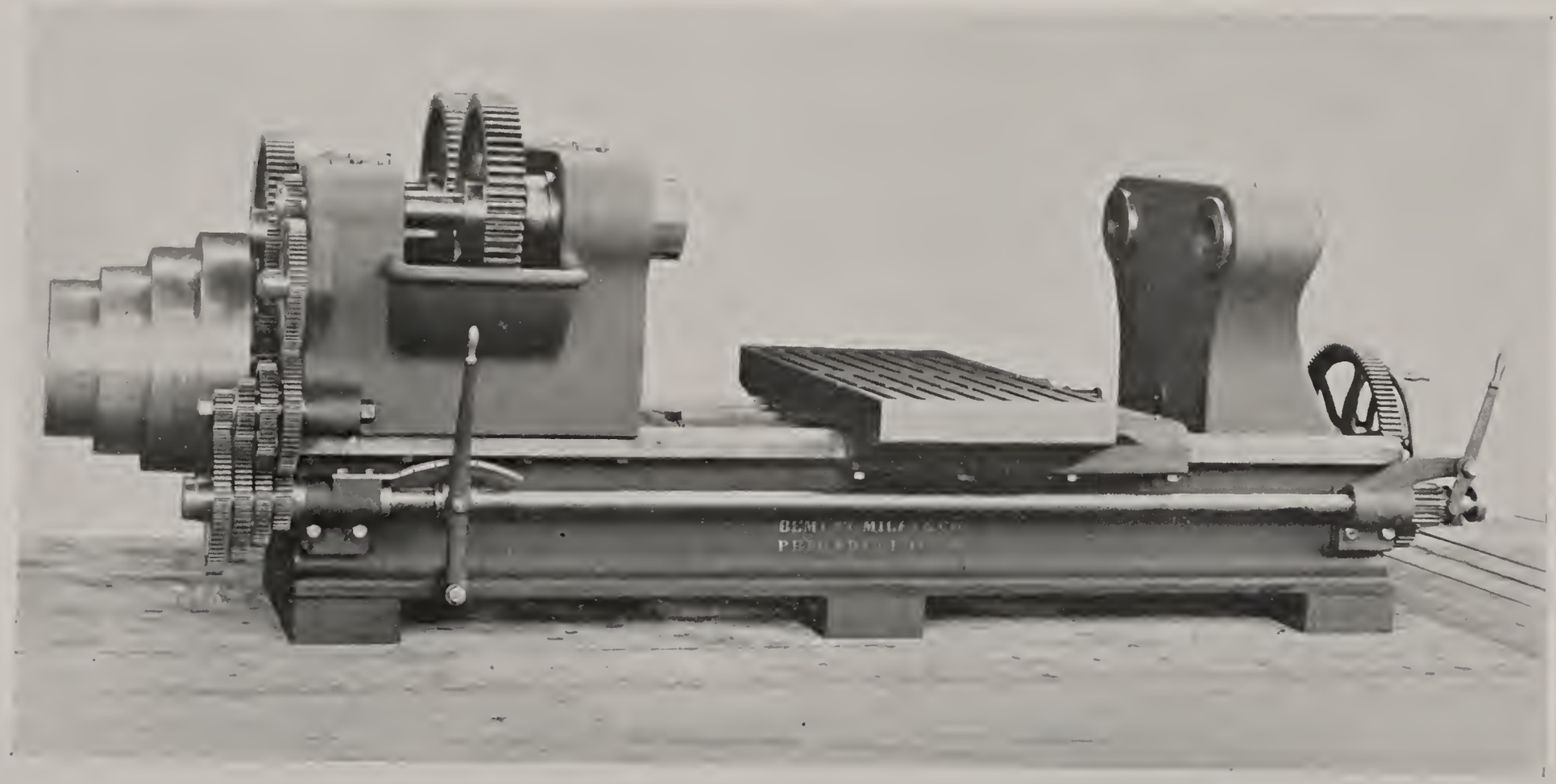

FIG. 65.

TWO-SPINDLE HORIZONTAL BORING MACHINE.

Niles-Bement-Pond Co., New York.

91. Miscellaneous Machines.

There are numerous varieties of boring and drilling machines which it is impossible to do more than mention here. As has been noticed, the boring machine comes very close to the milling machine in some of its adaptations. In fact, many such machines are milling machines, and will be discussed under that head.

Other types are used as rotary planers, so-called, if we may be willing to admit any distinction between the rotary planer and the milling machine. Tapping and thread-cutting attachments are frequently introduced, but in no way change the principle of the machine.

Multiple spindle machines for drilling and tapping belong rather to the class of drill presses, and will be treated under that division.

Special machines have been designed for boring engine frames and cylinders and for finishing generator and motor frames, while others have been built solely for use on structural work.

The larger machines of the horizontal class are good subjects for independent motor drives, and most of the machines just described are adapted for electric transmission.

The motor is usually of the constant high-speed type connected directly by gearing to the main spindle. The enormous size of some of these machines and the extent of floor space covered make electrical control particularly economical of time.

CHAPTER VI

DRILLING MACHINERY

92. The Upright Drill.

Convenience in handling and clamping the work, and facility for seeing what is being accomplished, have brought about the almost exclusive use of the upright machine for ordinary drilling. It may be found of almost any size and weight, from the so-called sensitive drill of Fig. 66 to the massive drill press of Fig. 70.

The ordinary drill press of the machine shop, having a capacity of from 24 to 36 inches, is in almost universal use, and next to the engine lathe may be regarded as the most necessary tool in the shop.

The elements of any upright machine are—

(*a*) The column.
(*b*) The drilling head and spindle.
(*c*) The table.
(*d*) The feed mechanism.

93. The Column.

The necessary height of this class of machine and considerations of stability have led to the general adoption of a hollow circular column with a broad base. In the sensitive drill, Fig. 66, the base is circular and merely serves as a support, while in the larger machines, as shown in Figs. 67 and 68, it is utilised as a floor plate for clamping large work.

In any type of machine, the circular section lends itself readily to the swinging of the table horizontally. Even in machines whose size has warranted the adoption of a massive rectangular housing, as in Fig. 70, the table is still swung from a supplementary round column.

The function of the column is threefold: to support the swinging table; to carry the tool head and spindle; to afford a support for the shafting.

It is in the adaptation of the column to this threefold use that the fancy of the designer has run riot. The tree form has evidently been the basis of design, as is natural, and we find all varieties of tree in evidence, from the graceful elm and the sturdy oak to the tropical banyan.

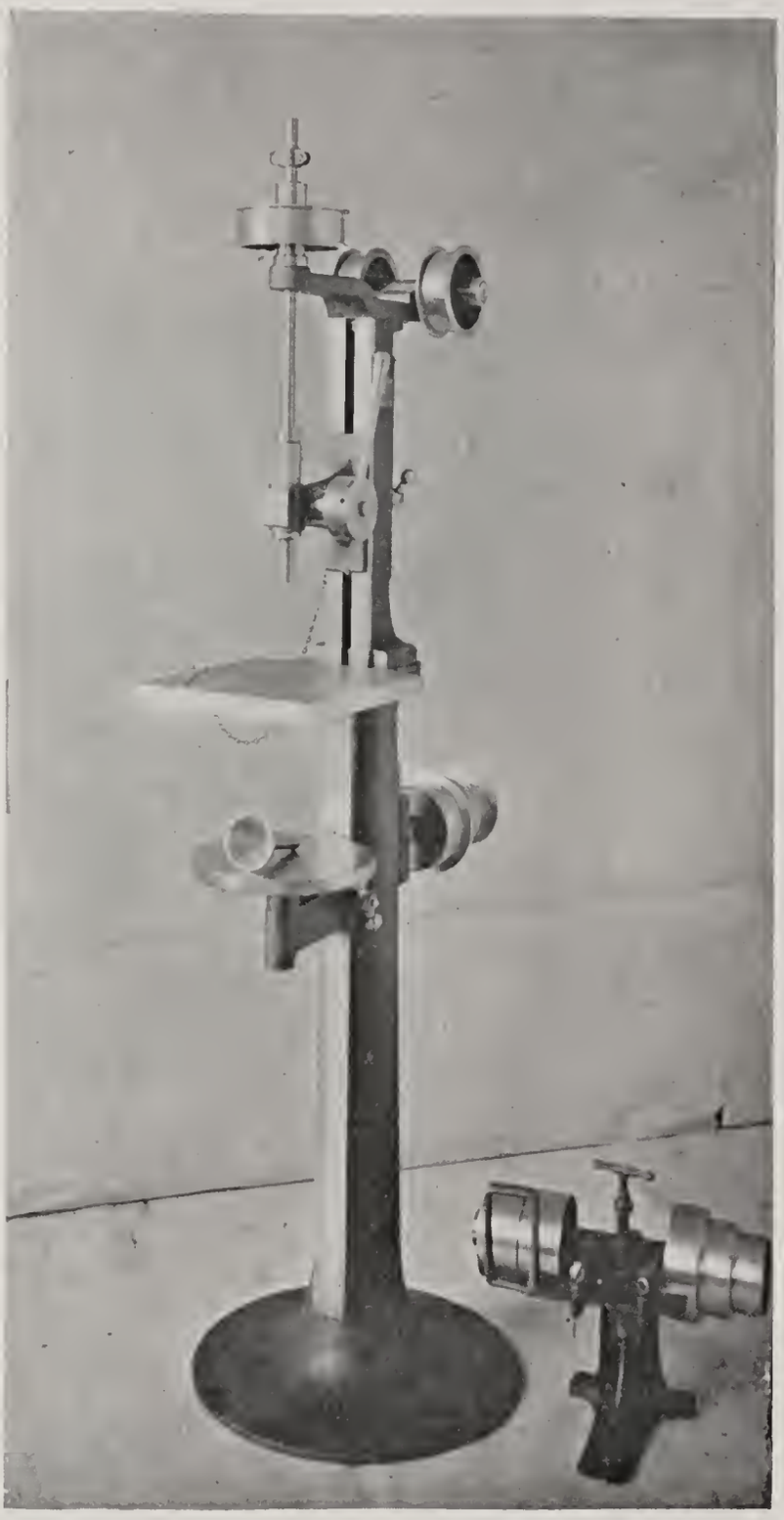

FIG. 66.

SENSITIVE DRILL.

The Dwight Slate Machine Co., Hartford, Conn.

For the support of the table, the column offers a smooth cylindrical surface, permitting the two motions of horizontal swinging and vertical adjustment.

As regards the tool head, it may be noted that the

column is subjected to a bending moment due to the upward pressure on the spindle, and that in ordinary drilling this is more severe than the twisting moment.

This bending moment will be uniform from bottom to top of column, and will then diminish uniformly as the column approaches the spindle. This indicates a column of uniform diameter and a goose-neck of diminishing diameter—see Fig. 67. If the top of the column is reinforced by the braces which support the shaft, its diameter may be correspondingly lessened. The secondary column in the rear, Fig. 68, helps to reduce the bending moment on the main column. A hollow column, exposed to a transverse moment, may be reinforced internally by flattening the core on two sides, making the section of an **O** shape.

Sensitive drills and machines having a capacity of 20 inches or less are usually built with but one column, and the shafting is supported by brackets at top and bottom as in Figs. 66 and 67.

In the larger sizes where double gearing is introduced at the top, most makers prefer to put in a secondary column to support upper and lower shafts and to brace the main column —see Fig. 68.

The design shown in the last-mentioned illustration is correct in principle and pleasing to the eye. In this machine, the secondary column is parallel to the first and is straight, as it should be, while the whole forms a well-balanced and symmetrical structure. Fig. 69, on the other hand, shows the application of the single column to a large and heavy machine, the makers depending on diameter and thickness of metal for the necessary rigidity. It is apparent from the cut that this machine will be stiff and strong, but there is not as good economy of metal as in Fig. 68.

The design is undeniably homely, there being too many offshoots from the parent stem to be pleasing to the eye. The absence of the lower countershaft and its brackets and appendages does, however, make the machine more compact and

more convenient to get at. It is possible for the operator to walk entirely round this machine without danger or difficulty.

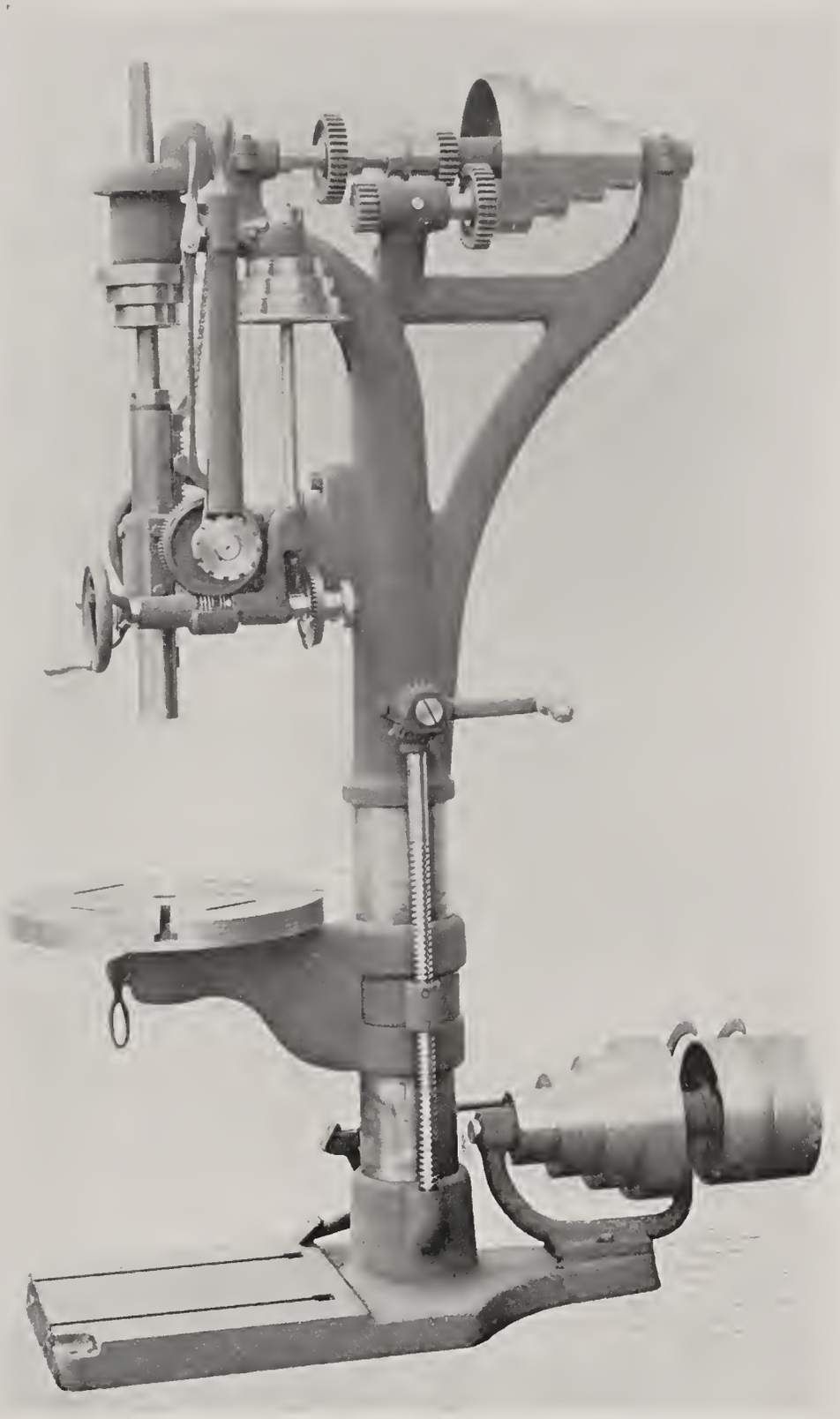

FIG. 67.

20-INCH DRILL PRESS.

American Tool Works Co., Cincinnati, Ohio.

For heavy and rapid cutting, the style of column shown in Fig. 70 possesses greater rigidity than any of these just

mentioned, being of the hollow box form and offering great resistance to bending. The table may be supported as shown, or the round column may be omitted and a table and bracket of the milling machine type be jibbed directly to the face of the cabinet.

94. The Head and Spindle.

The spindle, like that of the horizontal machine, must have the two motions of rotation and of longitudinal traverse.

It consists of a vertical steel shaft passing through two sleeves which give it the two motions mentioned. The upper sleeve is driven by a gear or pulley and imparts rotation to the spindle through a key; the lower slides vertically, carrying the spindle up and down by means of hardened steel collars. These collars are frequently provided with ball or roller thrust-bearings.

The motion of the spindle in the upper sleeve is sliding only, and the latter revolves in a bushing at the extremity of the goose-neck. The lower sleeve slides vertically without rotation in the head of the machine, being fed up or down by a rack and pinion.

It is in the attachment of the lower head to the column that we find the greatest variation among different machines. Machines, like those shown in Figs. 67 and 70, have this head cast to the column of the machine, and all the adjustment of cutting tool to work must be effected by the traverse of the spindle or the raising and lowering of the table. While this construction simplifies the feed mechanism and gives great rigidity to the head, it limits somewhat the adaptability of the machine.

For a wider range of work and greater convenience, the sliding head, as seen in Fig. 68, is preferred. Most manufacturers can supply either style, as desired. The sliding head is gibbed to ways on the front of the column, and can be adjusted up or down according to the height of the work, so

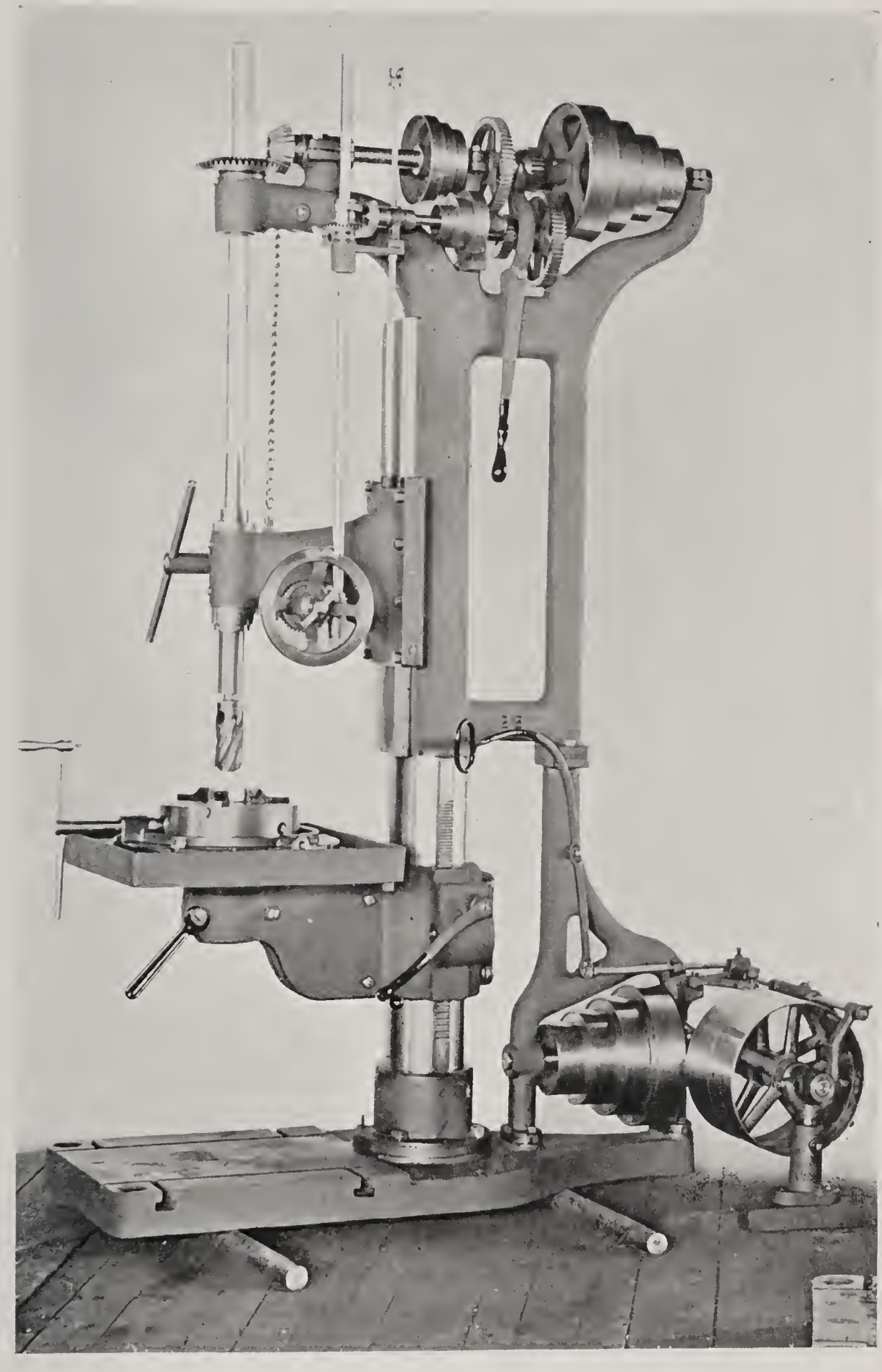

FIG. 68.

28-INCH UPRIGHT DRILL.

J. E. Snyder, Worcester, Mass.

as to support the spindle near the cutting tool. With a machine like that shown in Fig. 67, it is frequently the case that the spindle has considerable overhang, and does not afford firm support to the drill. This is especially true when drilling work on the floor plate.

In some machines the head is adjusted by hand, and is then clamped to the column, the feed being effected in the usual way by rack and pinion.

Fig. 68 shows a machine in which the sliding head itself moves up and down with the feed. The head has an extra long bearing on the column, and is driven by a pinion engaging with a stationary rack not seen in the figure.

This design does away entirely with the rack and pinion on the sleeve, and gives a much longer traverse than is practicable with the ordinary feed motion.

The 28-inch machine, shown in the figure, has a feed of 25 inches, which makes it particularly desirable for boring long holes or two holes which come in line.

A lever for quick return is provided, which makes it possible to raise or lower the head rapidly by hand. The head is counterbalanced by a weight inside the column.

The reverse of the usual arrangement is seen in Fig. 69, where the driving gear is at the lower end of spindle and the feed mechanism at the top. The advantage of this arrangement for heavy work is manifest, since the spindle is no longer subject to a twisting moment throughout its length and is less likely to spring and chatter.

The counterbalancing of the spindle should also be noticed.

95. The Table.

The table of the upright drill may be round or square, and may or may not swing in a horizontal plane, but it always has some vertical adjustment. Its most usual form may be seen in Fig. 67, a horizontal circular plate, capable of turning on its own axis and of being swung with its supporting bracket

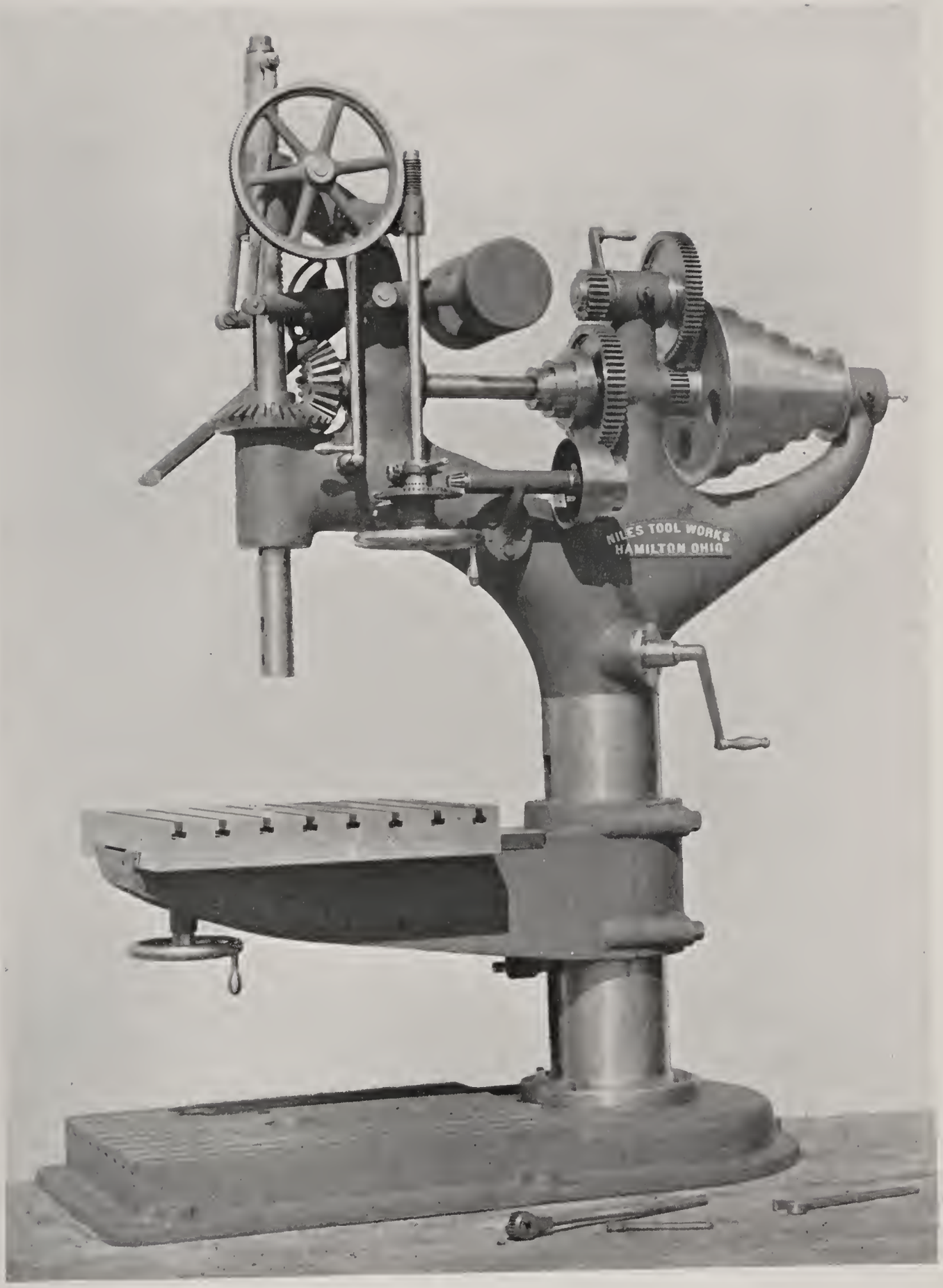

FIG. 69.

60-INCH VERTICAL DRILLING MACHINE.

Niles-Bement-Pond Co., New York.

about the circular column. It may be raised or lowered with the bracket, and may be rigidly clamped as to all three motions.

The raising or lowering of the brackets on the post is usually effected by a rack and pinion, as in Fig. 68, but Fig. 67 shows the use of a screw for this purpose. This latter method has the advantage of being more powerful and of bringing the elevating crank at a constant and convenient height for the operator.

In the sensitive drill, Fig. 66, the table has only the swinging motion, and a supplementary table is provided below for long work. This latter can be adjusted vertically on a dove-tailed slide cast to the column. Fig. 68 illustrates a square table fitted with a chuck for special drilling and boring. Machines of this latter class are sometimes equipped with a revolving table driven by power. This facilitates truing up the work and makes a substitute for the chucking lathe.

Some drills are equipped with a compound table similar to that of a milling machine, but operated by hand. All such devices tend to bring the drill into the milling machine class, much as has been noticed with the horizontal machines.

Fig. 69 shows a rectangular table with a horizontal adjustment to and from the column on parallel ways.

The machine illustrated in Fig. 70 has a bracket of unusual rigidity underneath the table, as befits a tool intended for heavy work.

Nearly all the machines illustrated have a lower table or floor plate, which is finished to a plane surface and provided with T-slots for the accommodation of large work.

96. The Gearing and Feed Mechanism.

The driving mechanism of the upright drill consists of a countershaft at the bottom provided with tight and loose pulleys and a stepped cone. The pulleys are usually so

arranged as to necessitate a quarter-turn belt from the line shaft, unless the machine is set parallel to the latter. The machine illustrated in Fig. 68 has its tight and loose pulleys at right angles to the countershaft, thus obviating the difficulty just mentioned. A somewhat similar arrangement may be seen in Fig. 70.

The upper shaft of the machine carries the second cone and the necessary double gearing for speed changes. This shaft usually drives the spindle through bevel gears. Most machines of this class have four steps on the cones, making, with the double gearing, eight changes of speed. The various illustrations show the manner of gearing quite clearly. Triple gearing is introduced on some of the larger machines.

There is considerable variety in the mechanism for feeding the spindle, depending on the style of frame and head adopted.

As has already been noticed, the vertical motion of the spindle is usually controlled by a rack and pinion. This pinion is turned by a hand-wheel for quick traverse, and by a worm and wheel which are engaged for the power feed. A lever feed is sometimes introduced at this point, as shown in Fig. 67.

The various speeds of the feed mechanism are obtained by stepped cones, which are located sometimes on the spindle itself, as in Fig. 67, and sometimes on the upper shaft, as in Figs. 68 and 69.

The use of the sliding head necessitates the splined vertical shaft for transmitting motion from the driving shaft above to the feed mechanism on the head. This arrangement is apparent in Fig. 68, as is also the automatic stop rod for controlling the depth of hole drilled.

The power feed can be disengaged by a clutch near the hand-wheel and the spindle fed slowly or rapidly by hand. Thus, the machine shown in Fig. 70 has a power feed, a hand-worm feed, a hand-lever feed, an automatic stop, and a quick return. Usually, three changes of feed are provided, but on

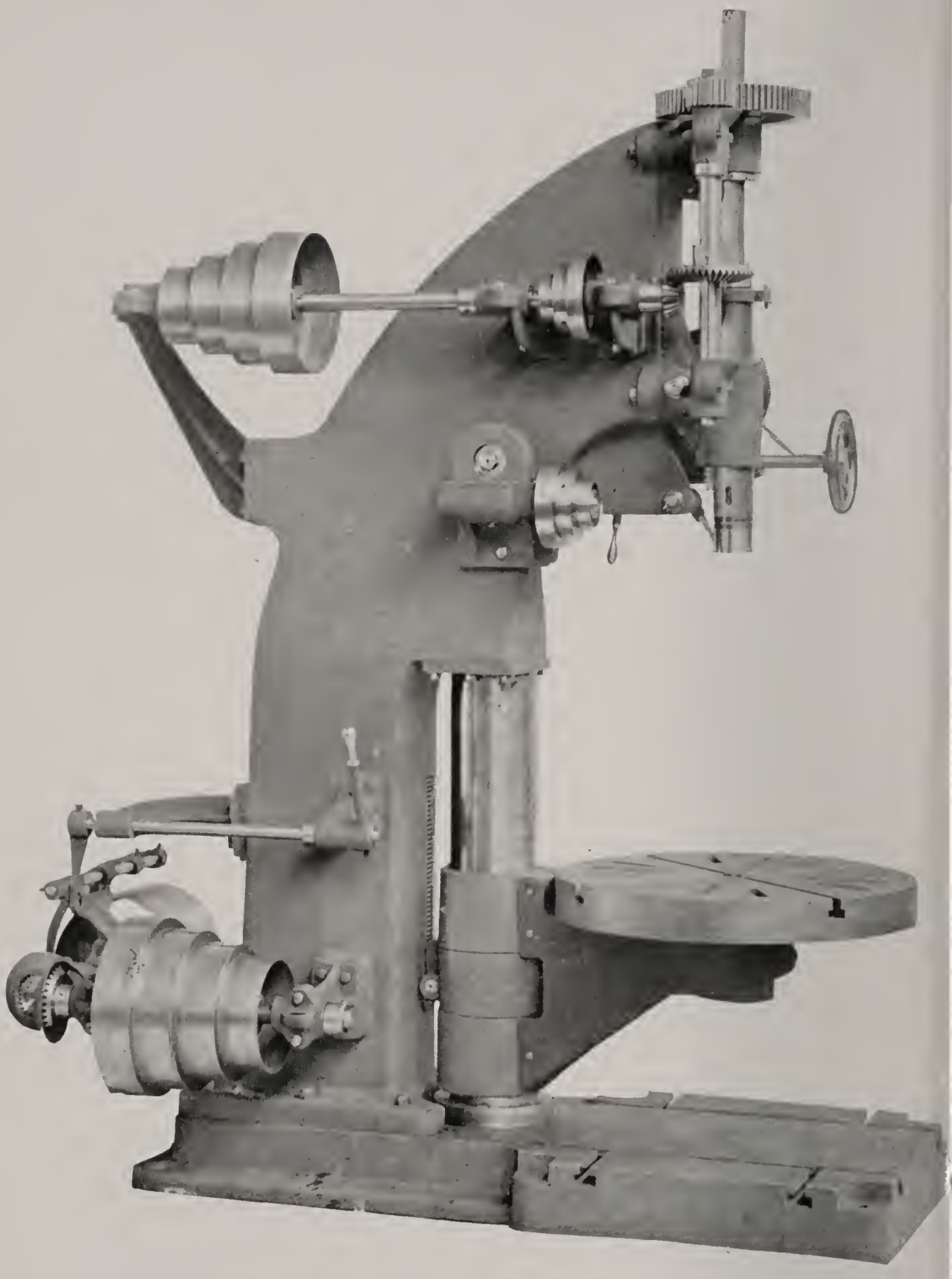

FIG. 70.

HEAVY DRILL PRESS.

Baker Bros., Toledo, Ohio.

some of the larger machines a geared feed is used, so that the machine may be employed for tapping.

97. Radial Drills.

In the ordinary upright drills which have just been con-

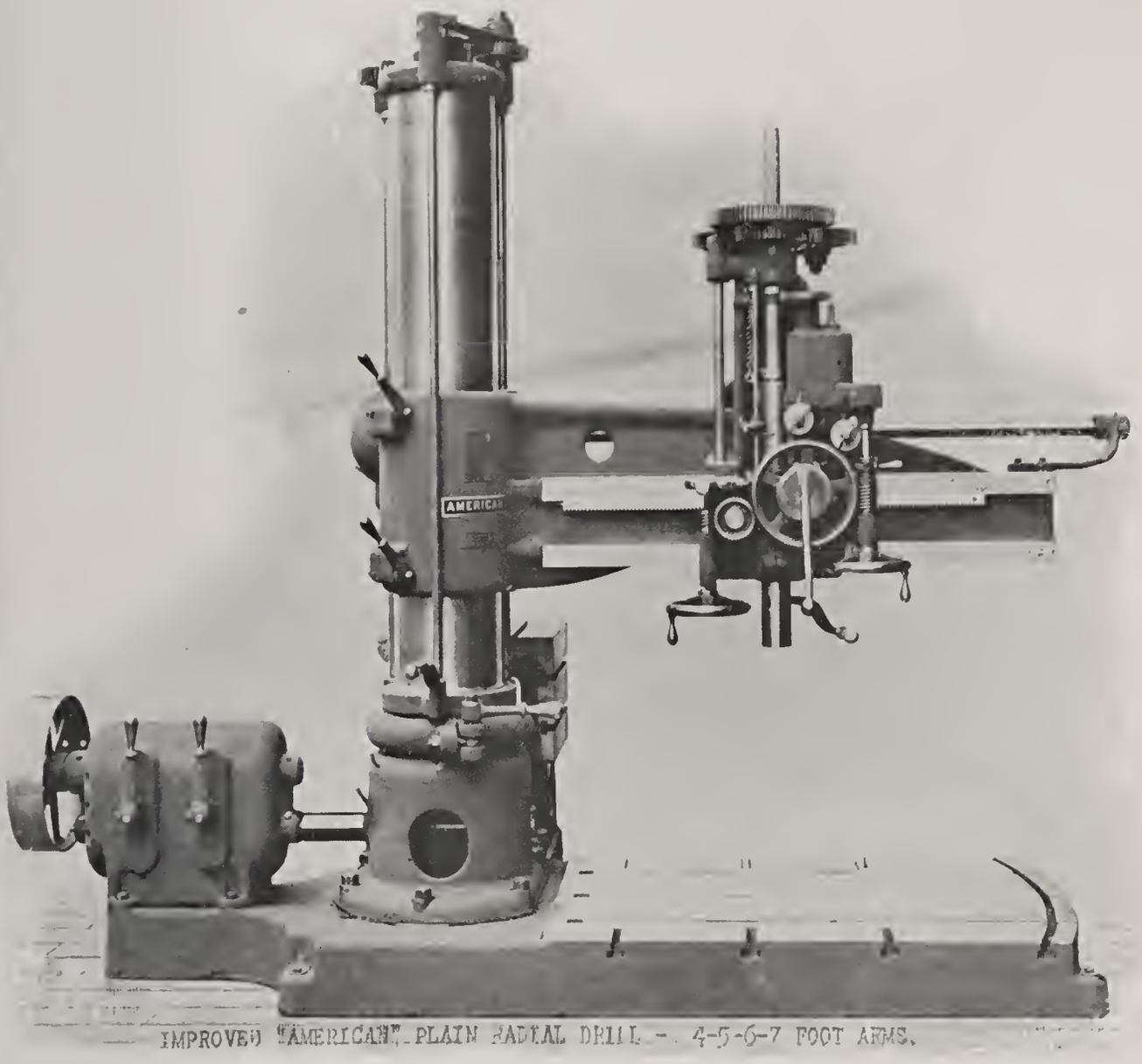

FIG. 71.

PLAIN RADIAL DRILL.

The American Tool Works Co., Cincinnati, Ohio.

sidered, the vertical axis of the spindle is stationary, and any side adjustment must be obtained by moving the work. As the size and weight of the work increases, we are confronted again by the old problem of whether it is cheaper to move the work to the tool or the tool to the work.

The radial drill is a concession to the latter principle, and

makes it possible to drill holes in a large casting or forging at almost any location or angle without moving it from its position.

Radial drilling machines have various degrees of freedom, and must be distinguished accordingly as plain, half-universal, or universal.

In the plain machines, neither arm nor head has any swivelling motion, and only vertical holes can be drilled. The half-universal machines have a swivelling head only, while the universal drills have both arm and head arranged to swivel, so that holes may be drilled at an angle. For the ordinary run of work the plain machine is the better adapted, as being simpler and more easy to operate.

The elements of the various machines are, however, much the same, and will be considered separately. They consist of—

(*a*) The column and its base.
(*b*) The radial arm.
(*c*) The tool head.
(*d*) The driving mechanism.
(*e*) The feed mechanism.

98. The Column and Base.

The base of the radial machine is much like that of its predecessor, the drill press—a massive floor plate with its upper surface planed and slotted for the accommodation of the work. To this base are bolted the column itself and the stand for the countershaft. Unlike its neighbour of the ordinary drill press, the column of the radial must stand alone, and instead of carrying the sliding head, must serve as a centre of motion for the radial arm.

There are, however, several types of column in common use which differ from each other in form and in principle. The favourite type is the double circular column, as illustrated in Figs. 71 and 72, and shown in detail in Fig. 73.

The outer sleeve is finished on the outside to fit the hub of the arm, so that the latter may slide freely from top to bottom. When the arm is adjusted at the proper height, it is clamped to the sleeve and the two then turn as one piece.

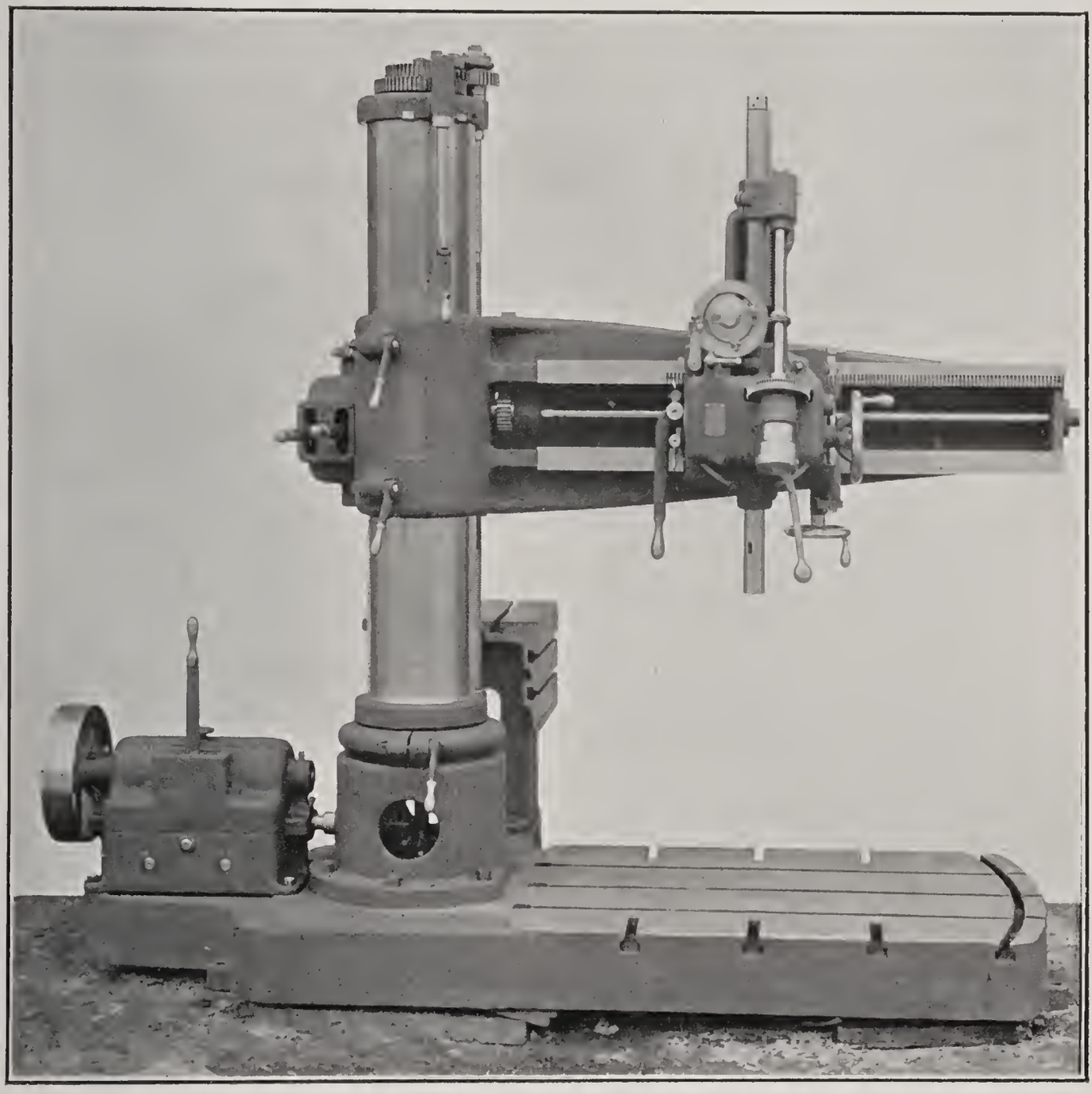

FIG. 72.

HALF-UNIVERSAL RADIAL DRILL.

Bickford Drill and Tool Co., Cincinnati, Ohio.

As may be seen by reference to Fig. 73, the sleeve has bearings at top and bottom on the inner column, the latter being in one casting extending from the base to the top of the machine. The sleeve rests at the bottom on a thrust bearing of conical rollers, which give it great ease of movement.

When in the desired position, it is clamped by means of the V-shaped ring at the bottom. As is shown more clearly in Figs. 71 and 72, this ring is split on one side and fitted with a clamping bolt and lever.

Finally, when both arm and sleeve are clamped in the desired position, the whole forms practically a single member free from joints and back-lash.

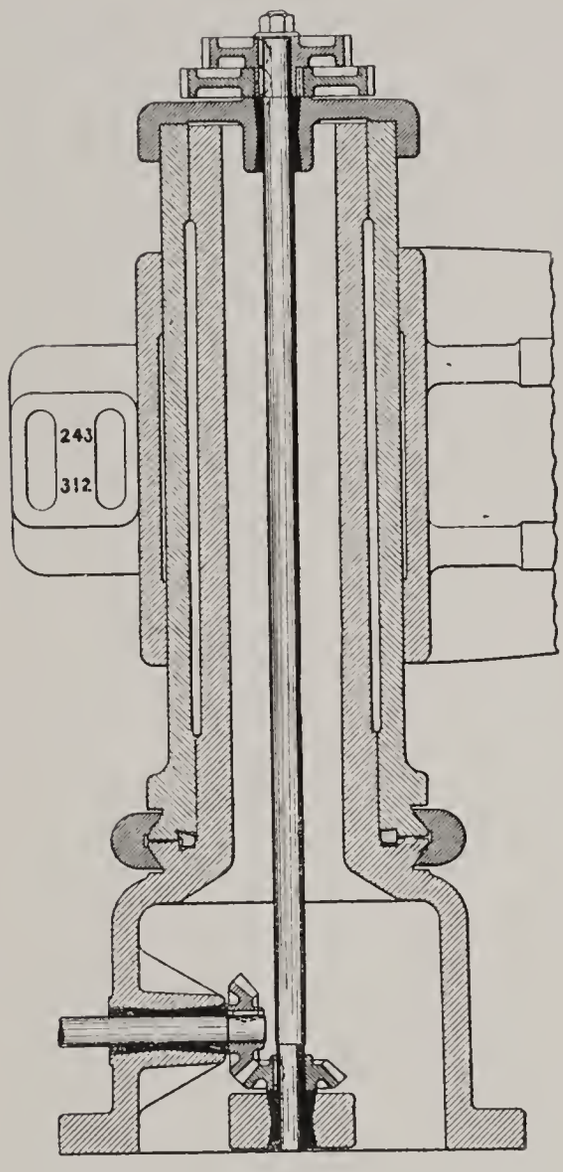

Fig. 73.

Column—Bickford Drill.

The sleeve and inner column together constitute a double hollow cylinder of the best section to resist the stresses due to bending and torsion.

The second type of column differs radically from the one just described, as may be seen by reference to Fig. 74. It consists of a post of a parabolic outline and of a box section having on the front flat ways for a sliding head, and carrying at the top a countershaft similar to that on an ordinary upright drill. In fact, the design differs from that of the sliding head drill only by the interposition of a radial arm between the saddle and the tool head. The saddle is gibbed to the rectangular ways and carries vertical bearings for the trunnions of the arm. The swinging motion is brought entirely away from the column, and provision is made on the latter for vertical movement alone.

While the arrangement just described may offer some advantages on the score of the convenience of manipulation, it does not seem to be so logical a design as that where the circular column is employed.

For a horizontal pressure, such as that exerted by the

cutting tool of a planing machine, the parabolic upright is correct.

In any form of vertical drilling machine, the principal pressure is that due to the point of the drill and is directly upwards. The resultant bending moment on the column will be the same from the bottom to the location of the radial arm, will be independent of the position of the arm on the column, and will depend only on the distance of the drilling axis from that of the column. The straight column is, therefore, correct for this class of machine. The rigidity of the combination, when drilling is being done at a large radius, is dependent upon the length of the vertical bearing of the arm on the column; and here also, the first-described design has the advantage, since the whole length of the column is available for this purpose. Lastly, the circular post allows the arm to swing completely around the machine, a freedom which is sometimes very convenient.

There are various modifications of the types just considered, one of which is shown in Fig. 75. This machine has a cylindrical column with the outer sleeve revolving on a roller bearing, but the radial arm slides vertically on rectangular ways, so that the design is a sort of compromise between the two types already considered.

99. The Radial Arm.

The arm, which constitutes the distinguishing feature of the radial machine, and gives its name, may have one, two, or three motions; the swinging about the column; a combination of this motion with vertical adjustment, as in plain radials; the addition of a swivelling motion on the column, as in universal machines. (See Fig. 76.)

Its shape is modified by the above-named conditions and by the type of column adopted. In general, it is of a tubular section reinforced by parabolic webs to take the bending moment. The stress due to this moment is the most severe

to which the arm is subjected, but there is also some torsion due to the spindle being at one side of the arm. The tubular

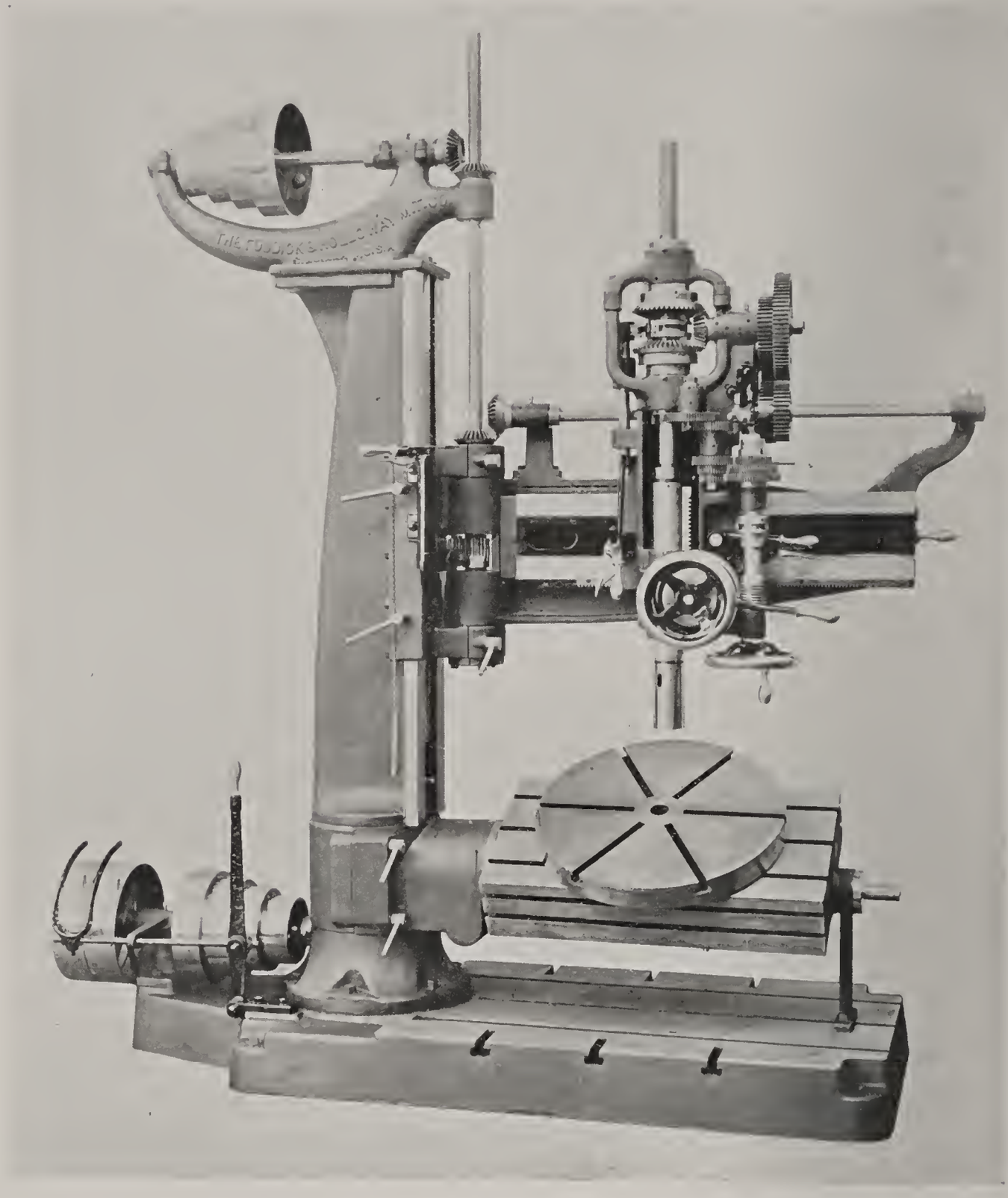

Fig. 74.

3-FOOT ARM RADIAL DRILL.

Fosdick Machine Tool Co., Cincinnati, Ohio.

section is well adapted to withstand stress due to the latter cause.

Flat ways are cast to the face of the arm for the spindle

head. Figs. 71 and 75 show a good design with the parabolic web above in the best position to withstand the bending action. This arrangement also leaves a clear space underneath and permits table and head to be brought close to column. Some radials have a design of a different character, the arm being kept straight on top to accommodate the gearing and a web added underneath. Neither on the score of strength nor of convenience is this arrangement as good as the other. The arms shown in Figs. 72 and 74 have the web above and below, a style which is symmetrical, but not so correct as that first mentioned.

When a circular column is employed, the arm has a split hub embracing the rotary sleeve and clamped to it by bolts with hand-lever nuts.

When the rectangular column is used, the arm has trunnions which turn in split bushings on a sliding saddle, and the bushings are clamped on the trunnions to secure the arm in position. Ball-bearings on the lower trunnion take the vertical thrust. The saddle slides on the rectangular ways of the column, and is clamped by gibs and screws in the usual manner.

Owing to the absence of any column bearing at the bottom, it is usually possible to bring the arm lower on the machine when the saddle is employed than when the arm embraces the column. Otherwise, the circular column type has the advantage in simplicity and rigidity. The raising and lowering of the entire arm and its attachments is effected by an elevating screw driven by power from the top of the column.

In the universal radial, Fig. 76, the arm is attached to the hub on the column by a swivelling joint. This permits the arm to be revolved on its axis by means of the worm and wheel shown, so as to drill holes at any angle in this plane of rotation. It is necessary in a universal machine to have the column revolve, to avoid too much complication in the saddle, but the type shown in Fig. 75 is sometimes adopted. In

such case, the arm swivels on the face of the saddle. Attention has already been called to the modifications in the attachment of arm shown in Fig. 75.

100. The Tool Head.

The tool head of the radial drill is practically that of a sliding head upright, transferred from the column to the radial arm and moving horizontally, instead of vertically. It must contain mechanism for revolving the spindle at the proper speed, for feeding it automatically towards the work, and for stopping and returning it quickly. Some machines have also attachments for tapping, while in all drills of the universal or half-universal class the head swivels on the arm. (See Fig. 72.) The ways on the radial arm are of the conventional type, and on these slides a saddle similar to those on a planing machine. The bearings for the spindle are cast or bolted directly to the saddle in the plain type of machine.

The spindle revolves inside a sleeve, the latter being provided with the usual rack and pinion for the vertical feed. The swivelling head, sometimes provided, turns on the saddle just as in a planing machine and makes the machine a half-universal so-called, while in combination with the swivelling arm it constitutes the universal mechanism. The traverse of the saddle on the arm is usually effected by a rack and pinion, although a screw is sometimes employed, as in Fig. 75.

101. The Driving Mechanism.

The most usual arrangement of shafts and gears for round column machines is partly shown in Fig. 73. The horizontal shaft drives through bevel-gears a vertical shaft which coincides with the axis of the column and operates gearing at the top. From these top gears are driven, first, the elevating

screw; and second, the mechanism for controlling the speeds and feeds of the spindle.

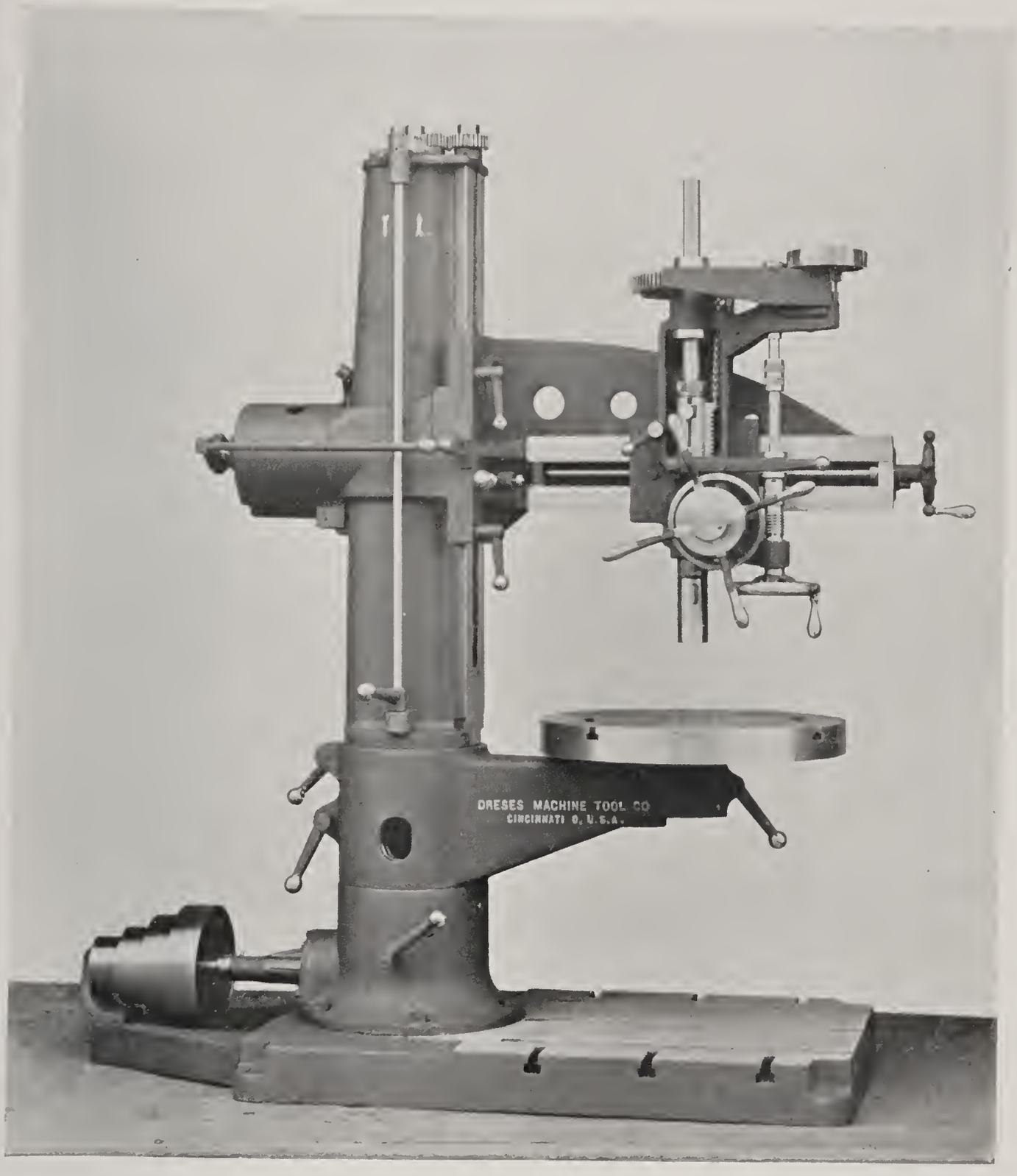

FIG. 75.

36-INCH RADIAL DRILL.

Dreses Machine Tool Co., Cincinnati, Ohio.

The gearing for raising and lowering the arm is started, stopped and reversed by the vertical rod and lever shown in Figs. 71 and 75 at the front side of the column. The driving

mechanism for the spindle is usually at the rear of the column. A vertical shaft driven by the top gearing is so splined as to drive the gearing on the arm, as the latter moves up and down; and as the top gear is concentric with the column, the whole arrangement can be turned around the column without disturbing the relations.

The back gears for changing the speed are located in the gear case at base of arm, and are so arranged that four changes of speed can be obtained by shifting levers on front side of case. Four other changes of speed are obtained by another gear case with suitable levers situated near the base of the column. (See Figs. 71 and 72.)

In the machine shown by Fig. 71, the back gears are located on the spindle head, so that the increased moment due to reduced speed is transmitted by the spindle alone. In either case, the combination of the two sets gives sixteen changes of speed, ranging in geometric progression from 16 to 267 revolutions per minute for drills of ordinary tool steel.

In machines, such as those shown in the two figures just mentioned, the use of an electric motor or of a belt from underneath will permit of the revolution of the arm completely around the column.

The machine, illustrated in Fig. 75, has a gear case on the arm, but the further changes of speed are obtained by means of a cone pulley.

The universal machine, shown in Fig. 76, is driven directly from overhead by motor or bevel gearing, but the speed changes are obtained by cone pulleys and back gearing located at the base of the arm. One advantage of this design is the fact that the base of the column is kept entirely clear of gearing and shafting, and this makes it possible to lower the radial arm close to the bed of the machine.

When the rectangular column is adopted there is necessarily a modification of the driving mechanism.

In Fig. 74 we see the tight and loose pulleys, the stepped cones and the overhead shaft of the ordinary upright drill.

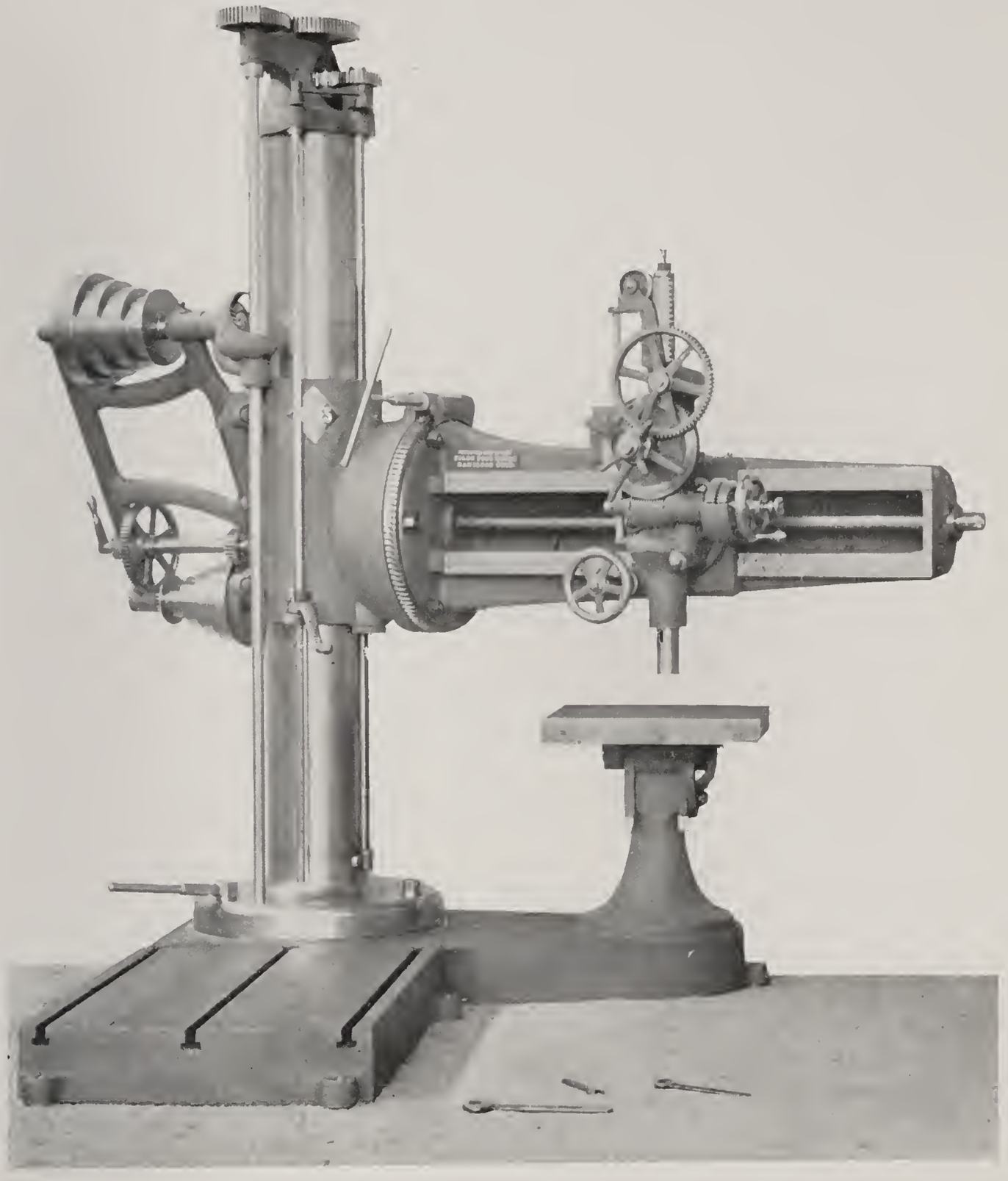

FIG. 76.

NILES UNIVERSAL DRILL.

Niles-Bement-Pond Co., New York.

The upright shaft is now concentric with the trunnions of the arm, and drives both elevating and spindle mechanism through trains of gearing. The back or double gearing is

located on the head, and, together with the cone, furnishes eight changes of speed.

The Baush radial drill has a belt drive through to the spindle with the double gearing directly on the latter. The overhead belting is similar to that of a sensitive drill, and by an ingenious device, the power is transmitted to the spindle head, as it moves to and fro on the radial arm. This same machine is also built with a geared drive similar to the one just described.

Speed cones are especially open to objection on radial drills, where changes of size of drill are frequent, and corresponding changes of speed are necessary to the best efficiency. The time and trouble incident to shifting a belt often prevent its being done. One objection, that may well be urged against belt transmission on machine tools, is the fact that they are usually out of repair and rarely in a condition to give the maximum efficiency.

102. The Feed Mechanism.

The mechanism for feeding the spindle vertically is naturally located on the head itself. By reference to Fig. 71 it may be seen that the rack sleeve outside the spindle is actuated by a pinion, and this in turn by a worm and wheel. A hand-wheel on the pinion shaft gives a quick motion for adjustment or return, and another on the worm shaft furnishes the regular hand-feed.

A gear case is conveniently located above the worm shaft, and two dials show the different rates of feed. On this particular machine eight feeds are provided, ranging in geometrical progression from ·007 inch to ·063 inch per revolution. A plate on the column shows the different sizes of drills used in the machine and the proper feed for each. The feed motion is driven by a friction device which will slip before anything breaks.

Most machines are provided with an automatic trip which

will stop the drill at any desired depth. Some drills have a graduation on the spindle, but the head shown in Fig. 72 is fitted with a dial register which can be set to zero when the drill enters the work and then the depth read without subtraction—a manifest advantage.

This particular head is also equipped with an automatic trip which can be so set as to act at different depths for the different holes to be drilled in one position of the work.

Most of the machines shown are fitted with special tapping mechanism when desired.

It is hardly worth while to describe the various feed mechanisms used by different builders, since they are in the main similar to the ones already mentioned, furnishing hand and power feeds, fast or slow, and quick return. Some machines have a belted feed motion, and in Fig. 76 is shown one with gear-shaft horizontal, instead of vertical.

103. Speeds and Feeds.

In all types of drilling machinery, whether horizontal or upright, stationary or radial, the question of the speed of revolution and of longitudinal feed is an important one on account of the character of the tools used. The modern twist drill is a standard tool for drilling holes in solid metal, and numerous experiments have shown approximately the best speeds and feeds for combined execution and endurance. Equip a machine properly for drilling holes in the solid, and there will be ample provision for the reaming and counterboring.

The speeds recommended by the Cleveland Twist Drill Co. are a peripheral speed of 30 feet per minute for steel, 35 feet per minute for iron, and 60 feet per minute for brass.

For drilling cast iron, the Bickford Drill Co. recommends speeds varying from 35 feet per minute for small drills to 15 feet per minute for drills over 3 inches in diameter. The following table gives the speeds for different sizes of drills

varying from $\frac{1}{2}$ inch to $3\frac{1}{2}$ inches in diameter, as listed by that company :—

Size of Drill.	Revolutions per Minute.	Cutting Speed. Feet per Minute.
$\frac{1}{2}$	267	35
$\frac{5}{8}$	222	36
$\frac{3}{4}$	184	36
$\frac{7}{8}$	153	35
1	128	33
$1\frac{1}{8}$	106	31
$1\frac{1}{4}$	88	29
$1\frac{1}{2}$	73	28
$1\frac{3}{4}$	61	28
2	51	26
$2\frac{1}{4}$	42	25
$2\frac{1}{2}$	35	23
$2\frac{3}{4}$	29	21
3	24	19
$3\frac{1}{4}$	20	17
$3\frac{1}{2}$	17	15

The makers and users of twist drills seem to be pretty well agreed on the question of speeds, but on that of feeds there is a marked difference of opinion.

The feed, formerly recommended by both the Cleveland and the Morse Twist Drill Companies, was ·005 to ·007 inch per revolution for drills smaller than $\frac{1}{2}$-inch diameter, and from ·007 to ·015 inch for larger drills. On the other hand, experiments made by the Bickford Drill Company, and reported in the *American Machinist* for July 24, 1902, have warranted them in adopting much coarser feeds, and using them on their own machines.

The subjoined table shows the eight feeds furnished on the radial drills manufactured by this firm and the corresponding sizes of drills :—

Size of Drill.	Feed per Revolution.
.....	·007 inch.
.....	·010 ,,
.....	·013 ,,
.....	·018 ,,
$\frac{1}{4}$ to $\frac{1}{2}$ inch,	·025 ,,
$\frac{1}{2}$ to 1 inch,	·035 ,,
1 to $1\frac{1}{2}$ inch,	·047 ,,
.....	·064 ,,

The four finer feeds are not to be used in regular work on cast iron, and the coarsest feed is intended only for reaming and finishing. Tests made by the same company were carried to the breaking of the drill, and showed that at a speed of 267 revolutions per minute a $\frac{3}{8}$-inch drill could not be broken at the coarsest feed of the machine, ·064 inch per revolution. A $\frac{5}{16}$-inch drill broke at this feed, and a $\frac{1}{4}$-inch at a feed of ·047 inch. In order that such feeds may be successfully used, it is necessary that the drill be held absolutely in line. The breaking of drills under heavy pressures is often due to the springing of the arm or head which holds the spindle and the consequent lack of alignment. The arm of a radial machine may spring in two ways—first, by bending; second, by twisting on account of the spindle being at one side of the arm. This latter is perhaps more apt to break the drill than the other, since the radius is less and the consequent angle greater.

To avoid this and get the greatest output from their machines, manufacturers should aim to keep the spindle as close to the arm as possible, and use a tubular section closed on both sides for the arm itself.

104. Tables.

Although the base of the radial drill is generally used as a support for the work, tables of various shapes and sizes are furnished when desired. The circular table mounted on a swing bracket is shown in Fig. 75, while in Fig. 74 we see the swivelling table, particularly useful with a plain radial. The plain box table is shown in several of the illustrations, sometimes mounted at the side of the base as an auxiliary. An elevating table, with tilting top which makes it universal, is used in some instances. The round column radial, such as is shown in Figs. 71 and 72, is sometimes fitted with a circular base extending around the column and having a radius equal to that of the arm. This makes it possible to

get work ready for drilling on one side of the base while the machine is finishing work on the other, thus economising time. Such a machine must be driven from overhead either by a motor or by bevel gears.

105. Power and Capacity.

There has been some confusion in the rating of sizes on radial machines due to their peculiar construction. When a lathe or upright drill is spoken of in this country as having a swing of 36 inches, the meaning is that the machine is capable of finishing a piece having that diameter.

On the other hand, a 36-inch radial drill, such as is illustrated in Fig. 75, is a machine having a clear radius for drilling of 36 inches. To avoid danger of misunderstanding, most manufacturers prefer to designate their machines as 3-foot arm, 4-foot arm, etc., this being understood to be the maximum distance from outside of column to centre of drill spindle. Where a column has a projecting base, this distance should be measured from outside of base. The flange on the base should be cut away, as in Fig. 72, to ensure the possibility of getting the entire range of the machine on heavy work. The electric motor is particularly serviceable on radial drills, as they are large machines and of such a shape that belt drives limit their use.

A common arrangement is that where a constant-speed motor takes the place of the ordinary driving pulley, the changes of speed being effected by gearing. The sizes of motors recommended by the Prentice Company are as follows :—

3-foot arm,	1	h.p.
4-foot arm,	2	,,
5-foot arm,	2	,,
6-foot arm,	3	,,
7-foot arm,	3	,,
8-foot arm,	$7\frac{1}{2}$	,,
9-foot arm,	10	,,

Fig. 77 shows a variable-speed motor taking the place of the usual speed box at the base of the column, and having electric speed-control by variation of the field resistance. The same number of speeds are available as when the speed box is used.

Most makers are prepared to furnish motor drives

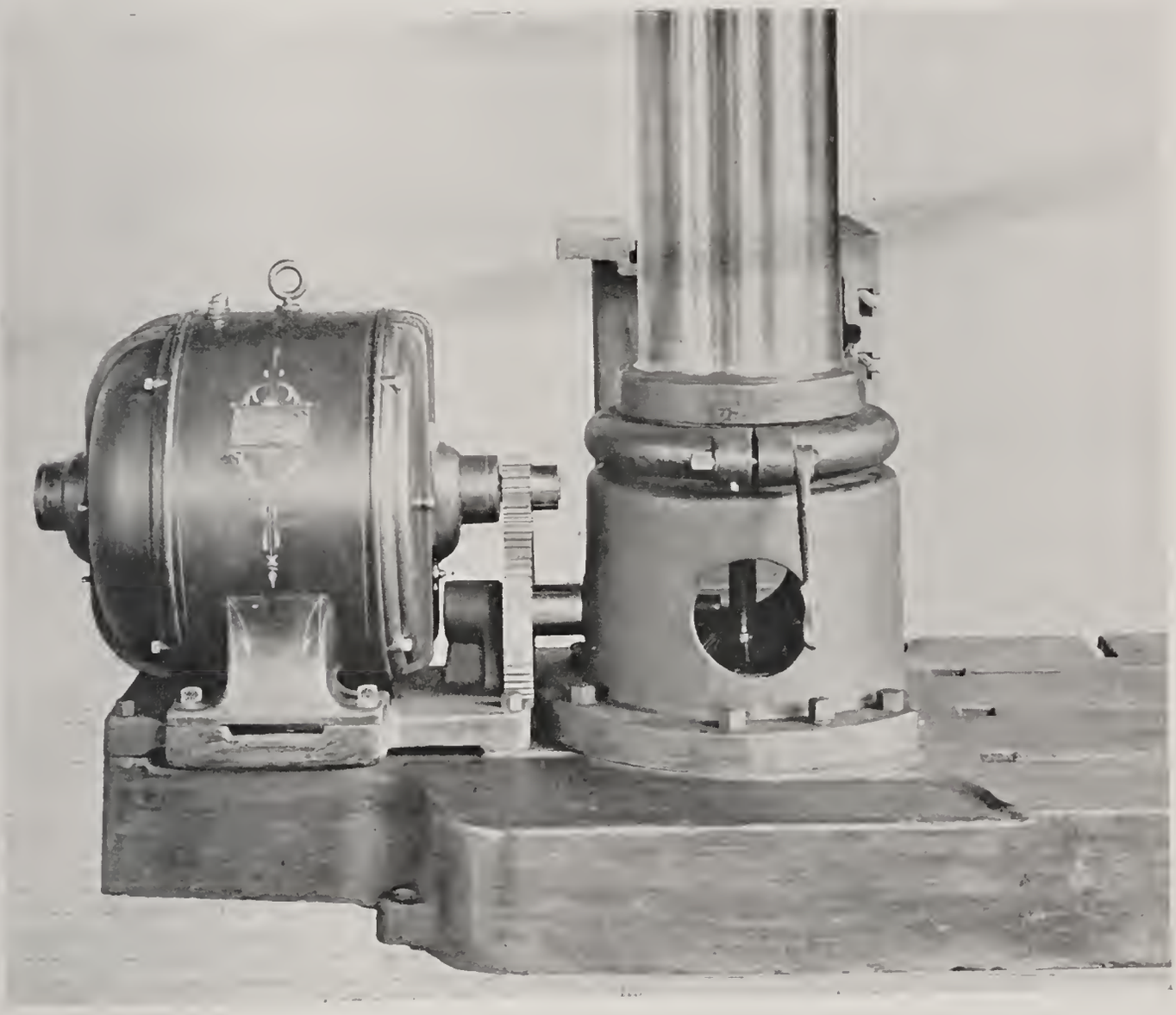

Fig. 77.

ELECTRIC DRIVE, VARIABLE-SPEED MOTOR.

The Bickford Drill and Tool Co., Cincinnati, Ohio.

either geared or connected by silent chain with the driving mechanism, and with either constant or variable speed.

More specific information with regard to the power consumed in drilling may be found in a later paragraph.

106. Miscellaneous Machines.

There are several varieties of drilling and boring machines which do not come under any of the foregoing classifications and should receive separate mention. One of these is the wall radial, in which the column is omitted, and a radial arm, similar to that shown in Fig. 74, is supported on a frame fastened to a wall or column of the building. In the plain wall radial the arm always remains at the same height, while in the adjustable machine the arm is pivoted to a sliding saddle which can be raised or lowered on the frame. Even simpler than the above is the post drill, where a plain bracket projecting from wall or post carries the drill head and spindle, the power feed and other complications being omitted.

A modification of the radial drill for heavy work is the so-called universal drill. The arm carrying the spindle head is no longer radial, but is swivelled at both ends to uprights on either side of the bed. The uprights are joined by a top brace making a gallows frame, and giving rigidity to the whole design. The arm, now become a cross-rail, is capable of being raised or lowered in the frame, swivels to any vertical angle, and carries a swivelling head. The machine is thus universal, and can drill and bore at any angle.

For drilling holes in flat plates of unlimited extent the suspension drill is a convenient machine. Being suspended from the ceiling, it leaves a clear space underneath. It is provided with power feed, and has eight changes of speed. A modification of this type sometimes used on large structural work has the drilling head suspended from a travelling crane, and capable of being moved in any direction horizontally. The drill is operated by an electric motor.

107. Multiple Drill.

Drilling machines do more work than formerly, and do

better work because they are more rigid in construction and more convenient in operation. Another cause for increase of output, which deserves special mention, is the multiplication of cutting edges in the same machine.

Multiple drills, so called, like turret lathes, are well adapted to the production of interchangeable work in large quantities. When a casting or forging has on one face a number of parallel holes of the same or nearly the same size, the drilling of the holes simultaneously by one machine results in a great saving of expense if the process is repeated a sufficient number of times to pay for the initial adjustment of the machine.

Fig. 78 illustrates a small drill press of the multi-spindle type, capable of carrying twelve drills from $\frac{1}{32}$ to $\frac{1}{4}$ inch in diameter. The general design of the machine is especially neat and pleasing to the eye. The head, which holds the spindles, is stationary, and the feed is obtained by moving the table. The latter is furnished with a long bearing on the column, and is operated by a lever for the size shown. A stop, seen at the rear of the table, may be set at any desired point. The spindles are driven by double Hooke's joints from a ring of vertical shafts above, and are so guided by adjustable arms that they may be arranged according to almost any pattern.

It is easy to set the drills in the jig to be used, to adjust the spindles to match, and finally to clamp the arms in position. Multi-spindle machines are well adapted to drilling holes in flanges, hubs, and couplings, and in the covers of cylinders and valve chests. While the illustration shows a small size, machines of this same type can be had in various sizes up to one which will drill $1\frac{1}{4}$-inch holes in a circle of 36 inches diameter. The larger machines have a stationary table or base and a sliding head to give the necessary feed.

A machine having a less degree of freedom than the ones just described is the gang drill (Fig. 79), where the different spindles are arranged side by side on a cross-rail, so that the

holes drilled come in one straight line. As may be seen from the figure, the cross-rail is usually stationary, and the

FIG. 78.

PRATT AND WHITNEY MULTIPLE DRILL.

The Niles-Bement-Pond Co., New York.

vertical adjustment is in the table, which can be raised and lowered by two screws. The heads may be from two to

eight in number, and can be adjusted on the rail independently by means of rack and pinions. The spindles can be driven and fed simultaneously by power, but are so arranged that any one may be disconnected and operated independently by hand. The particular machine shown has

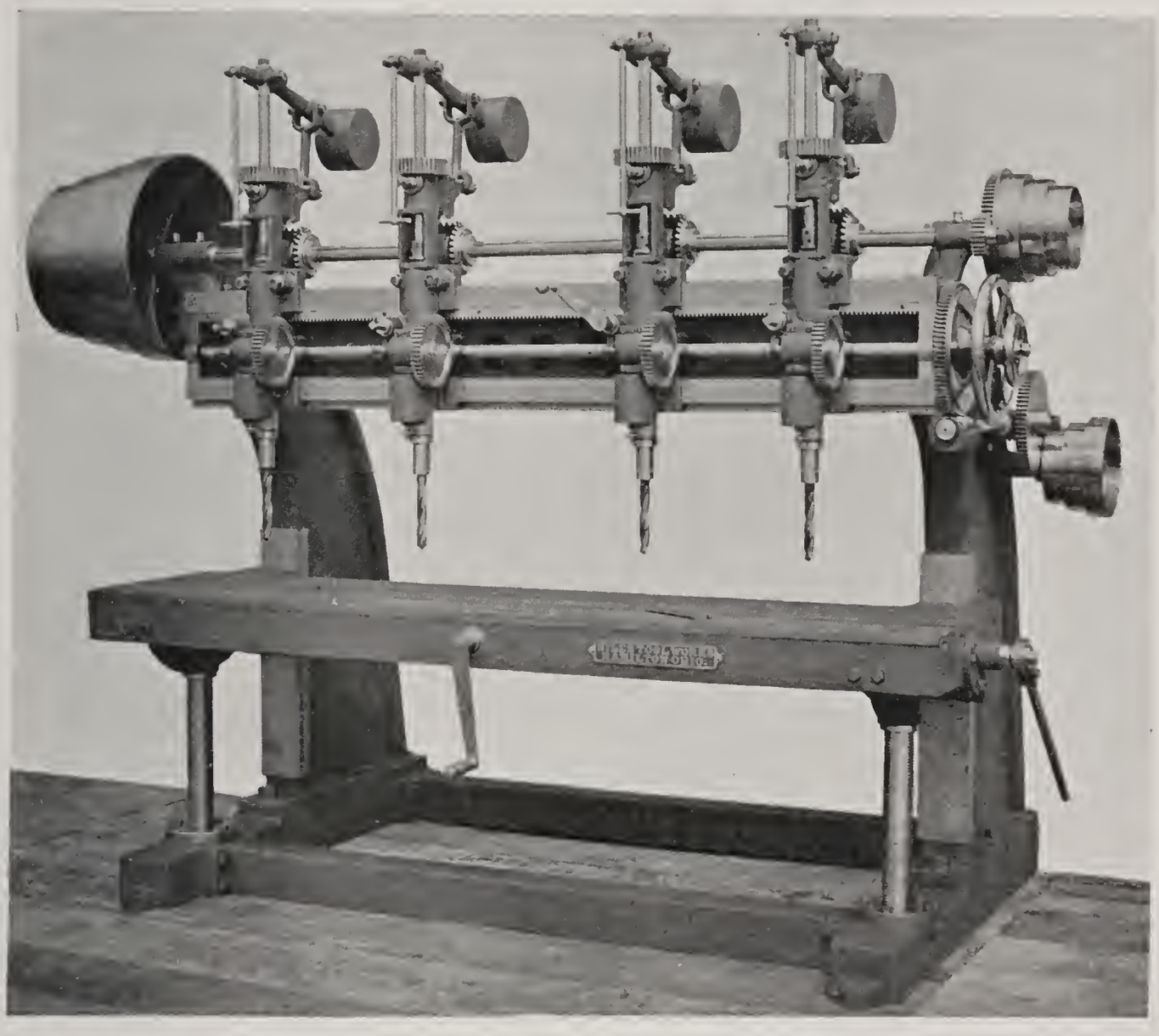

FIG. 79.

NILES STANDARD MULTIPLE DRILL.

The Niles-Bement-Pond Co., New York.

four speeds and three feeds, and is intended for $1\frac{1}{4}$ inches maximum diameter of drills.

Machines of the same type are built with six or eight spindles driven from either end in two groups and capable of carrying drills 2 inches in diameter.

Multiple drills of this character are mostly used for drilling rows of holes in the edges of doors, plates, or covers of a rectangular shape.

The traverse-table machine resembles a planer in general appearance, having a bed with two uprights and a cross-rail, and being equipped with a platen sliding on V-shaped ways. As the platen slides at right angles to the plane of the drilling spindles, it is possible to drill a series of rows of holes without re-setting the work.

There is evidently no limit to the number of combinations that may be made by different arrangements of spindles, heads, and tables, and it would be superfluous to attempt to catalogue many of them here.

The machines which have not already been illustrated and described can be regarded in the light of special tools intended for a limited range of work. The railroad car and locomotive shops of the country are usually equipped with such special tools, and some of the larger engine works are similarly provided for. Special lathes and boring mills for such shops have already been described. A large size of two-spindle drilling machine is intended for use on connecting and parallel rods and heavy work of a similar character. The cross-rail is stiffened by a middle upright, and the two heads are entirely independent of each other as regards driving and feeding mechanism.

Fig. 80 shows the adaptation of the multiple-spindle principle to a horizontal machine for the purpose of drilling holes in the flanges of long pipes and columns too long to be handled in a vertical machine. All the adjustments and feeds are in the head itself, which slides lengthwise of the bed, and can be controlled by power or by hand. Where the flanges of short columns or cylinders are to be drilled the machine is made with a head at each end, and the two flanges are drilled simultaneously. In such case the two heads are made entirely independent of each other.

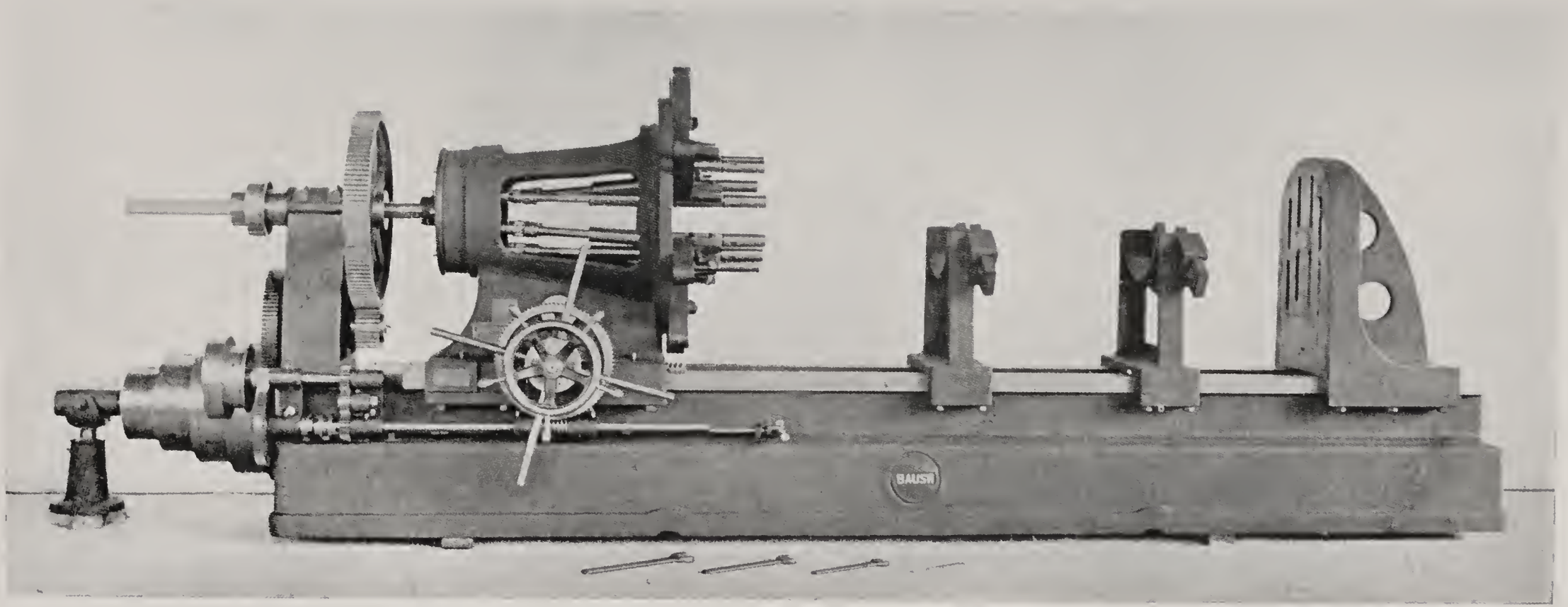

Fig. 80.

EIGHT-SPINDLE MULTIPLE DRILL.

The Baush Machine Tool Co., Springfield, Mass.

108. Power required for Drilling.

In drilling holes through the solid metal two resistances need to be overcome—the vertical pressure on the point and the tangential resistance to cutting. Numerous experiments have been made by the Cleveland Twist Drill Company with a special drill press of their own devising, some of which were reported in the *American Machinist* for May 30, 1901.

Tests of a $1\frac{1}{4}$-inch drill, making sixty-six revolutions per minute and having a feed of ·0075 inch per revolution, gave the results summarised in the following table :—

Material Drilled.	Pressure on Point.	Tangential Pressure at Periphery.	Horse-Power.	
			Due to Point.	Due to Cutting.
Cast Iron, . .	660 lbs.	576 lbs.	·0008	·377
Machinery Steel, .	1120 ,,	928 ,,	·0014	·608
Tool Steel, . .	1760 ,,	1328 ,,	·0022	·870

Pressures, such as noted above, depend largely upon the way in which the drill is ground. It is to be supposed that the drills used in these experiments were ground as long experience had shown that they should be ground. It is apparent that, as far as power is concerned, the point pressure is ineffective, except in so far as it increases the friction of the machine.

The point pressure is, however, the principal factor in determining the strength and rigidity of the drilling machine.

It is in radial drills, with their long reaches and off-sets, that this is most apparent. From the figures just given it may be seen that a radial machine with a 4-foot arm would have a bending moment at the column of $48 \times 660 = 31{,}680$ lbs. inches when using a $1\frac{1}{4}$-inch drill on cast iron at the full reach,

and nearly twice this when drilling machinery steel. If the off-set of spindle is 5 inches measured from the axis of tubular arm, the twisting moment on the arm due to point pressure would be 3300 lbs. inches when drilling cast iron, and 5600 when drilling machinery steel, under above conditions.

The actual horse-power consumed in drilling can be better understood from a series of experiments made by the Bickford Drill and Tool Company at Cincinnati, Ohio, and published in the *American Machinist* for January 14, 1904.

These experiments were made with drills varying from $\frac{1}{2}$ inch to $1\frac{1}{2}$ inches in diameter and feeds varying from ·0155 to ·035 inch per revolution. The material drilled was cast iron, and the speed of each drill such as to give a cutting speed of from 30 to 35 feet per minute. Under these circumstances the horse-power required for each size of drill at the same feed was nearly the same, while the horse-power per cubic inch of metal per minute was much greater for the smaller sizes.

The gross horse-power (*i.e.* including the power required to run the machine itself) was, in brief, as follows :—

$\frac{1}{2}$-inch drill,	1·82	to	2·79	horse-power.		
$\frac{3}{4}$,,	,,	1·78	,,	3·06	,,	,,
1 ,,	,,	1·61	,,	2·89	,,	,,
$1\frac{1}{4}$,,	,,	1·74	,,	3·30	,,	,,
$1\frac{1}{2}$,,	,,	1·66	,,	3·29	,,	,,

The horse-power per cubic inch of metal per minute varied from about 2 in the $\frac{1}{2}$-inch drill to about ·75 in the $1\frac{1}{2}$-inch size.

Experiments were also made on cast steel, wrought iron, and machinery steel. The following conclusions are voiced by the author, Mr. H. M. Norris :—

(1) When the speed and feed are constant, the power required to drill cast steel is about 1·10 times, wrought iron about 1·65 times, and machinery steel about 1·90 times that required to drill cast iron.

(2) When the speeds and feeds remain constant, the power required is approximately proportional to the diameter of the drill.

(3) When the diameter of the drill and the rate of feed are constant, the power required is approximately proportional to the speed.

(4) When the speed and diameter of drill are constant, the power required is approximately proportional to the feed.

The horse-power per cubic inch of metal per minute is not far from the average in other machine tools. Tests made by the writer at various times have shown this to vary from 0·5 to 2 horse-power under changing conditions when lathes, boring mills, and planing machines were the tools tested.

The installation of electric motors for drilling machinery has shed some light on the question of power. A comparison of some of the installations already made shows the following to be current practice :—

Machine.	Horse-Power of Motor.
30-inch upright, . . .	2
36 ,, ,, . . .	$2\frac{1}{2}$
40 ,, ,, . . .	3
4-foot radial, . . .	2
5 ,, ,, . . .	3
6 ,, ,, . . .	5

Some tests made on a 5-foot radial drill cutting cast steel gave 2·1 for the total horse-power, of which the machine itself absorbed 1·1 horse-power.

109. High-Speed Drilling.

The use of air-hardening steel for twist drills is as yet rather experimental, but is destined soon to work a revolution in drilling, as in other machine processes.

The reports on work of this kind come to us mostly from English sources, and at the present writing England seems to be in advance of America in this important development.

A paper read recently at Coventry by Mr. J. M. Gledhill contains, amongst other interesting material, the following remarkable records of actual performances by twist drills made by A. W. Steel :—

Diameter of Drill.	Material Drilled.	Speed.		Feed.		Endurance.
		Revs. per min.	Feet per min.	Inches per rev.	Inches per min.	Inches Drilled.
$\frac{3}{4}$-in.	Gray Iron	360	70	·0167	6	548
1 ,,	,, ,,	250	65	·0167	4·16	312
1 ,,	Steel	250	65	·0200	5·	300
$1\frac{1}{4}$,,	,,	...	...	...	2·14	...
2 ,,	,,	80	42	·0104	0·833	620

The author of this paper states that it is entirely possible to run drills at a speed of 400 feet per minute and a feed of 25 inches per minute when cutting cast iron.

Assuming one horse-power per cubic inch of cast iron per minute for a 1-inch drill, the 1-inch drill mentioned in the preceding table would consume about 3·25 horse-power.

The chief advantage in the use of the high-speed steel seems to be in the durability of the drill, a comparison of one of these drills with an ordinary American drill showing 620 inches drilled by the former as against only 40 inches drilled by the latter. Furthermore, the ordinary drill was ruined by the test, while the other was uninjured.

It must be remembered, however, that, as in other machines, the use of the new steels in drilling machinery means a re-designing of the entire tool to secure the increased power, speed, and strength which are necessary.

CHAPTER VII

MILLING MACHINES

110. Advantages.

Twenty-five years ago the milling machine was regarded as a special tool, and the bulk of straight work was done on the planer and the shaping machine. To-day the milling machine is in the lead, and is preferred by most manufacturers for all work within its range. The reason for this is the simple fact that this machine will do more work, or will do the same work with a greater degree of accuracy. The milling cutter is a multiple tool having many cutting edges, and it has no return motion, but cuts all the time. Furthermore, the possibility of shaping irregular outlines by one operation, and of repeating that operation, and thus duplicating the pattern indefinitely, gives the milling machine a great advantage over machines using a single-point tool. Even in the simple operation of facing plane surfaces, the milling cutter with inserted teeth has made records which no reciprocating machine can hope to equal. The fact that both types of machine are to-day working side by side in the best shops shows that each is finding its own proper field, and succeeding in that field.

111. Classification.

Milling machines may be classified in several different ways, according to the position of spindle, the style of frame, or the movement of the table.

(1) The spindle is usually horizontal; vertical spindles being used only for special work such as profiling or die sinking.

(2) The style of frame most common is the column or cabinet, with the table supported on a knee bracket. The so-called Lincoln machine has a frame similar to that of a lathe, with head and foot-stocks, and has a vertical adjustment for the spindle. The 'manufacturing machine' is rather a cross between the Lincoln and the column styles, and is used for making small parts in large numbers. A description has been given of the heavy machines of the planer type in the chapter on planing machines.

(3) Column milling machines are classed as plain or universal, according to the freedom of movement of the table. In the plain machine the table always stands at right angles to a vertical plane through the spindle, while in the universal machines it can be swivelled to any angle in the horizontal plane for the purpose of milling spirals. By the term 'hand-milling machine' is meant one whose table feeds, both vertical and horizontal, are operated by hand.

112. Column Machines.

In discussing the details of milling machines, all those having column or cabinet frames will be considered together since they possess the same general characteristics. The elements of such machines are—(*a*) the column and its base; (*b*) the table and its supporting bracket; (*c*) the spindle and head; (*d*) the driving mechanism; (*e*) the feed mechanism; (*f*) the various attachments for head and table.

113. The Column.

The rectangular cabinet similar to that already described in the chapter on shaping machines is in almost universal use. It assumes various shapes, according to the size of the

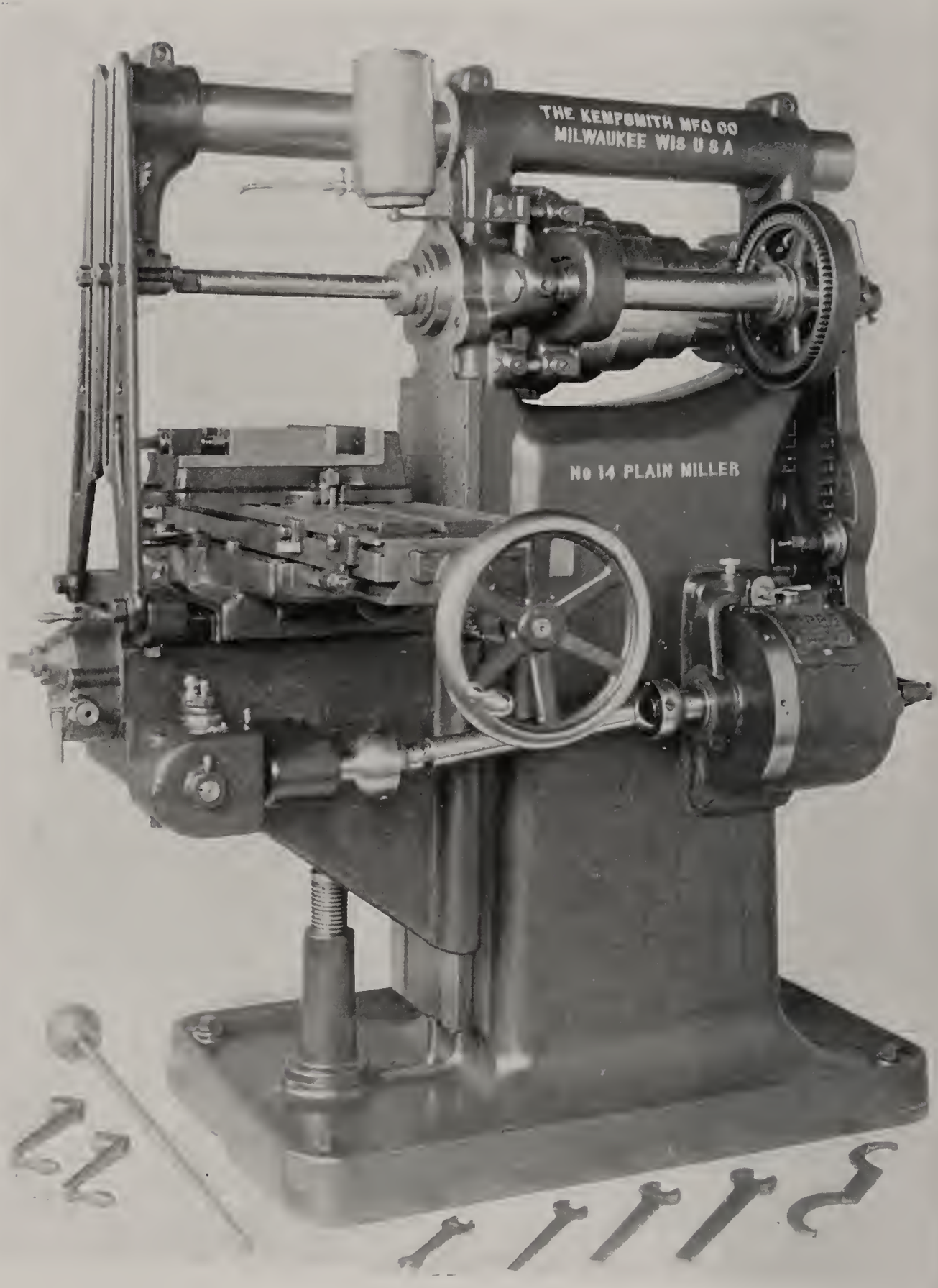

FIG. 81.

NO. 14 PLAIN MILLING MACHINE.

The Kempsmith Manufacturing Co., Milwaukee, Wis.

machine, from the slender proportions in the hand machine to the massive contours of the one shown in Fig. 82, but the general design is the same in all. Some builders prefer to make the base slope smoothly to the floor, as in the last-named figure, while others make it with a rim to catch oil and chips, as in Fig. 81. The head is in nearly all cases cast directly to the column without any dividing ridge or moulding. Two bevelled ways on the front surface are guides for the bracket which supports the table. Weight and stability are the main features of the design, and these are particularly necessary in a machine so prone to chatter as the milling machine. Small machines are provided with an oil pan underneath the table, and all the machines shown have closets and shelves for convenience' sake.

114. The Table.

In the column type of machine the head is stationary, the cutter revolves in one plane, and all the motions for adjustment and for feed are in the table. As has already been noticed, the principal support of the table is a bracket or knee as it is generally called, sliding vertically, with gibbed bearings on the front of the column. The gibs are tightened by clamp bolts and levers, so as to hold the knee firmly at any height. The vertical adjustment is effected by a screw underneath. This latter is made telescopic in most machines, so that it is unnecessary to have it run through the floor, as may be seen by reference to several of the illustrations. A ball bearing is frequently used to take the thrust of the elevating screw. The hand wheel for operating the screw is shown clearly in Fig. 84 standing obliquely at the left of the knee. The knee has a long bearing on the column, and is braced underneath by triangular or parabolic flanges. Bevelled ways on top of the knee guide the saddle, which slides to and from the column parallel to the spindle. The saddle is actuated by a screw, and in all the larger machines

the feed is automatic. When the table alone is to be fed, the saddle can be clamped in position.

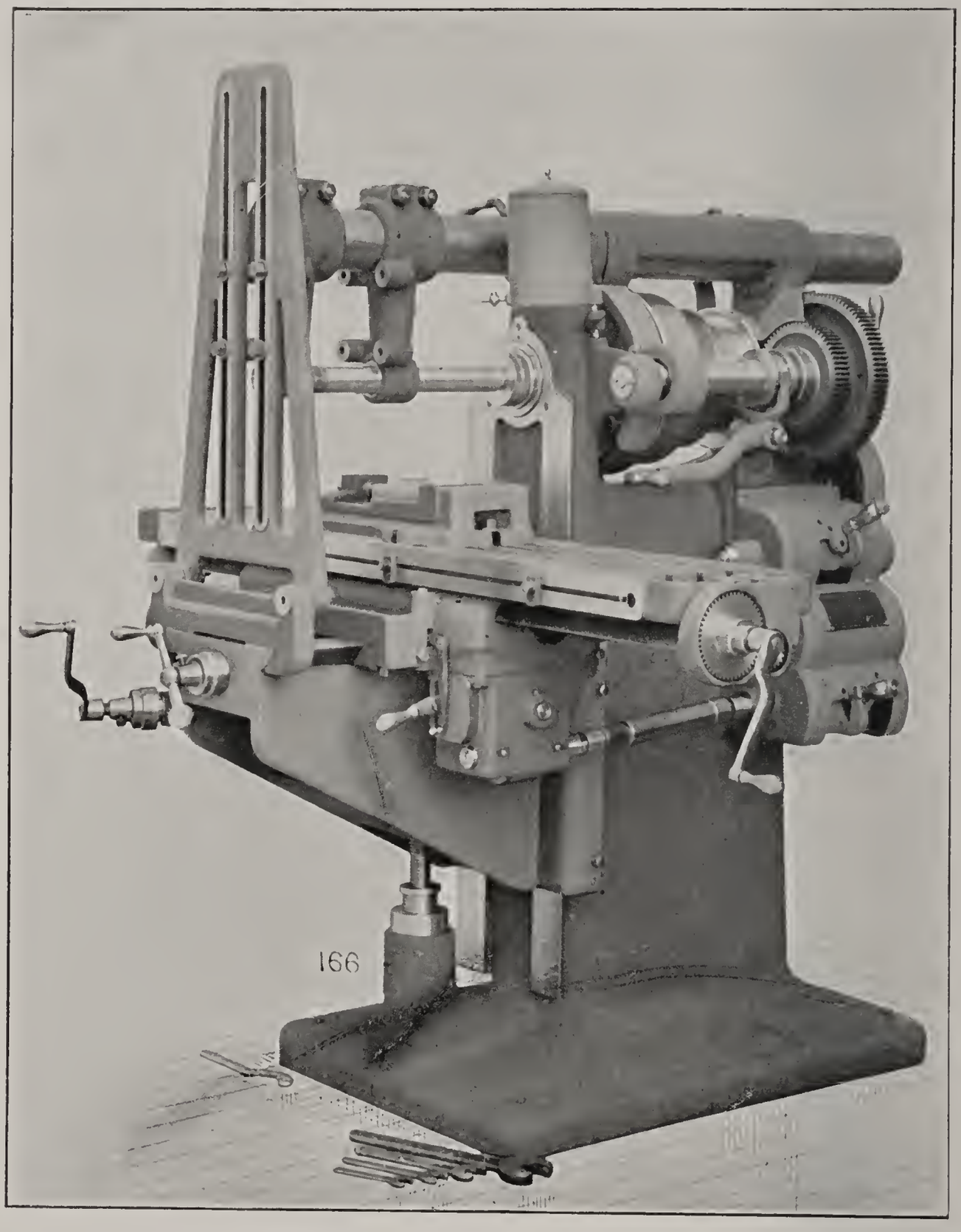

FIG. 82.

NO. 3 PLAIN MILLING MACHINE.

R. K. Le Blond Machine Tool Co., Cincinnati, Ohio.

We come now to the parting of the ways between the plain and the universal machines. In the former, illustrated

in Figs. 81 to 83 inclusive, the table slides directly on top of the saddle in dovetailed ways provided for that purpose, and as a consequence always moves at right angles to a vertical plane through the axis of the spindle. On the other hand, in the universal machine a turn-table is mounted upon the saddle and carries upon its upper surface the guides for the table. The latter can thus be swivelled so as to travel at any angle in the horizontal plane and permit oblique and spiral forms to be cut. While the universal machine is indispensable for certain classes of work, it is not so good a machine for the ordinary work of the shop as its relative. The introduction of the extra joints complicates the feed mechanism and makes the table less firm, while the space occupied by the turn-table reduces the vertical capacity of the machine.

The swivel or turn-table can be set 45 degrees either side of the middle position without disturbing the automatic feed of the table. It has a large bearing surface on the saddle, and can be clamped in any position by bolts.

The table in all machines, plain or universal, is much the same in design, being a box-casting with the conventional dovetail slide at the bottom, and with slots for bolts at the top. It has an automatic feed on the saddle, and can be clamped at any desired position. The front edge is slotted for adjustable blocks, which act as automatic stops to the feed motion. To sum up, the table has three motions, any or all of which can be made automatic at will, while the universal table has in addition the swivelling motion.

The various hand wheels and cranks for controlling all of these various feeds and adjustments are so located as to be easily reached from the front of the machine, a feature which is to be especially commended.

115. The Spindle and Head.

The character of the work which a milling machine is called upon to do necessitates particular care in the design of

the spindle that it be true and rigid, and that its bearings may always be in line as they are adjusted for wear.

Spindles as a rule are made of crucible steel having a

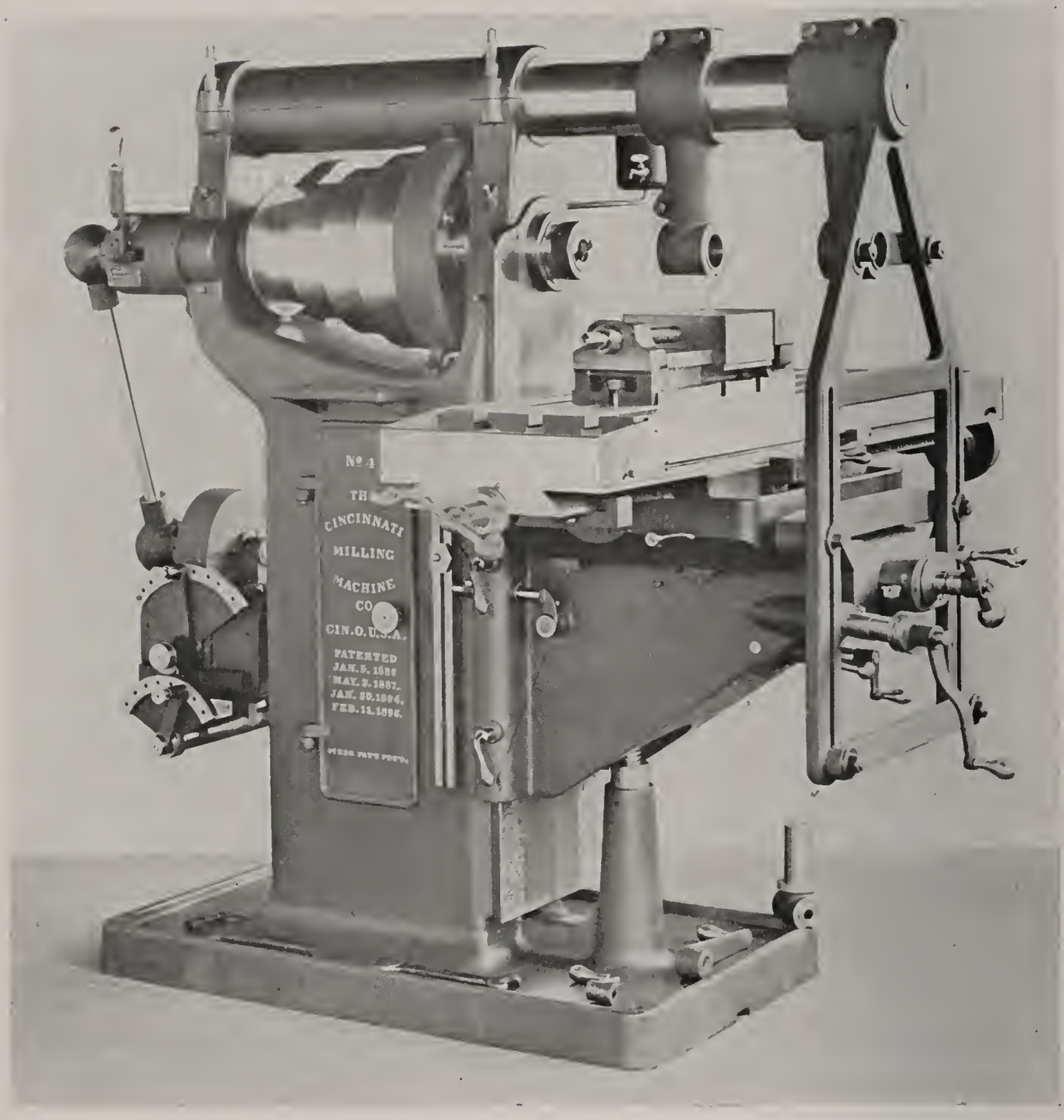

FIG. 83.

NO. 4 PLAIN MILLING MACHINE.

Cincinnati Milling Machine Co.

rather high percentage of carbon, with journals accurately ground to size and running in bronze or babbited bearings.

Experiment and practice has brought about a practically uniform design for the bearings of the spindle. The front journal is conical, and adjustment is effected by crowding it

back in the bearing. The rear journal is straight, having a split box fitting a conical hole in the head, and adjusted by lock nuts at each end. Fig. 85 shows the method of adjustment of the front bearing. A lock nut on the inner end of the box crowds back the spindle by pressing on the hub of the face gear.

The spindle, as it wears, is thus kept accurately in line. It has a hole through it from end to end, and is fitted at the front end with a standard taper hole for arbors and an external thread for chucks. This thread, when not in use, is protected by a cover nut, and a dust cap on the end of the spindle protects the bearing from dirt.

Nearly all milling-machine heads are at the present time equipped with an overhanging arm for the purpose of steadying the outer end of the arbor. This is hung in bearings cast to the head above the spindle, and can be adjusted for different lengths of arbor or turned entirely out of the way when light work is being done. In the smaller machines the arm takes the form of a goose neck at the end. The support for the arbor in the heavier machines is a separate casting bored to fit the arm, and sometimes two of these are provided, as shown in Fig. 83. Both supports are fitted with bronze bushes, which are split and can be adjusted to a snug bearing on the arbor. The arm itself in such cases is usually made of steel, and has a long bearing in the head, with powerful clamping bolts. (See also Fig. 82.) A machine sometimes has one arm with two bearings, one a bush and one a centre, for use on heavy and on light work. To further stiffen and strengthen the machine when taking heavy cuts, braces are attached to the front arbor support, connecting it firmly with the saddle, as in Fig. 81, or with the knee itself, as in Fig. 82. When the work and the arbor are properly adjusted, these braces can be set in place and bolted, making practically a footstock for the machine, and increasing the stiffness in a marked degree. Fig. 83 shows still another arrangement, where the brace is bored for the end of the overhanging arm.

In some of the larger sizes of machines the braces are carried to the base of the column and serve to stiffen the knee as well as the arm.

The whole design of the spindle, the head, and their attachments is such as to afford a firm support and perfect alignment for the cutter when doing the heavy and rapid work which modern manufacturing methods demand.

116. The Driving Mechanism.

Speed cones, usually of four steps, are employed in the same manner as on lathe spindles, and are used in combination with double gears to obtain the desired speeds. A two-speed countershaft raises the number of different speeds to sixteen. The machine shown in Fig. 82 is double back-geared, with three steps on the cone, thus having nine speeds for each countershaft speed, or eighteen in all. There is a friction device for throwing in the back gears so that speed can be changed quickly.

In all the geared machines shown shields are provided to cover the gears and prevent accidents.

The speeds provided for depend, of course, upon the size and capacity of the machine. The standard dimensions recently agreed upon by American manufacturers, and closely representing current practice, are as follows :—

Plain Milling Machines.

No. of Machine.	0	1	1½	2	3	4	5
	In.	In.	In.	In.	In.	In.	In.
Transverse movement,	6	7	7	8	10	12	12
Vertical movement, .	15	19	19	19	20	20	21
Automatic table feeds,	18	24	24	28	34	42	50

Universal Milling Machines.

No. of Machine.	1	1½	2	3
Transverse movement, .	7 in.	7 in.	8 in.	10 in.
Vertical movement, . .	18 in.	18 in.	18 in.	19 in.
Automatic table feeds, .	20 in.	20 in.	25 in.	30 in.

A comparison of three different makes of plain machine gives the following as about the average speeds recommended :—

Spindle Speeds.

No. of Machine.	0	1	2	3	4	5
Changes of speed, .	8	8	16	16	16	18
Slowest speed, . .	60	60	16	12	10	10
Fastest speed, . .	360	300	400	360	360	360

The speeds are given in revolutions per minute. Each set of speeds is supposed to form a series in geometrical progression. Surface speeds of from 20 to 60 feet per minute are recommended, depending upon the nature of the material and the character of the cut.

The subject of high-speed milling will be discussed in the latter part of this chapter.

117. Feed Mechanism.

It is in the range and power of the feeds that there has been the most conspicuous improvement of late years. Formerly an automatic feed for the table controlled by small cone pulleys of three steps was all that was considered necessary. To-day all the feeds are automatic, have an extended

range of speeds, and in the heavier machines are positively driven by gears. The use of the double Hooke's joint with telescopic shaft is almost universal as a means of driving the table mechanism in all its different positions. In Fig. 81 is shown a gear box driven by chain from the spindle and having sixteen changes controlled by three levers. The speed boxes are similar to those already noticed on lathes and drilling machines, and are gradually supplanting belt feeds in all machine tools for heavy service.

Machines such as the one shown in Fig. 82 have belt feeds in No. 2 and smaller sizes, but gearing in the larger ones. With the gear box shown in the cut sixteen changes can be obtained by the use of two levers.

The machine illustrated in Fig. 83 has an inclined shaft and bevel gears which transmit motion from the spindle to the lower gear box. One change lever is located at the top giving two speeds, and the other changes are obtained by levers at the gear box. The machine shown in Fig. 84 has the feed actuated by a chain.

There is some variation in the feeds specified by the different manufacturers of milling machines, the finest being from ·002 inch to ·007 inch and the coarsest from ·15 inch to ·35 inch per revolution, the latter figure being for large machines like No. 4 or No. 5. There are from twelve to twenty changes of feeds, according to the make of machine, the feeds like the speeds increasing in geometrical progression. The reason for this is apparent when one considers that the cutting speed depends on the size of the cutter as well as the number of revolutions. With a small cutter and a high spindle speed a fine feed per revolution of spindle is desired; while with a large cutter and low spindle speed a coarse feed is needed to give the same travel of table per minute. The following tables are copied from the plates attached to a Brown and Sharpe No. 2 Universal Milling Machine and show the speeds and feeds available and the manner in which they are obtained :—

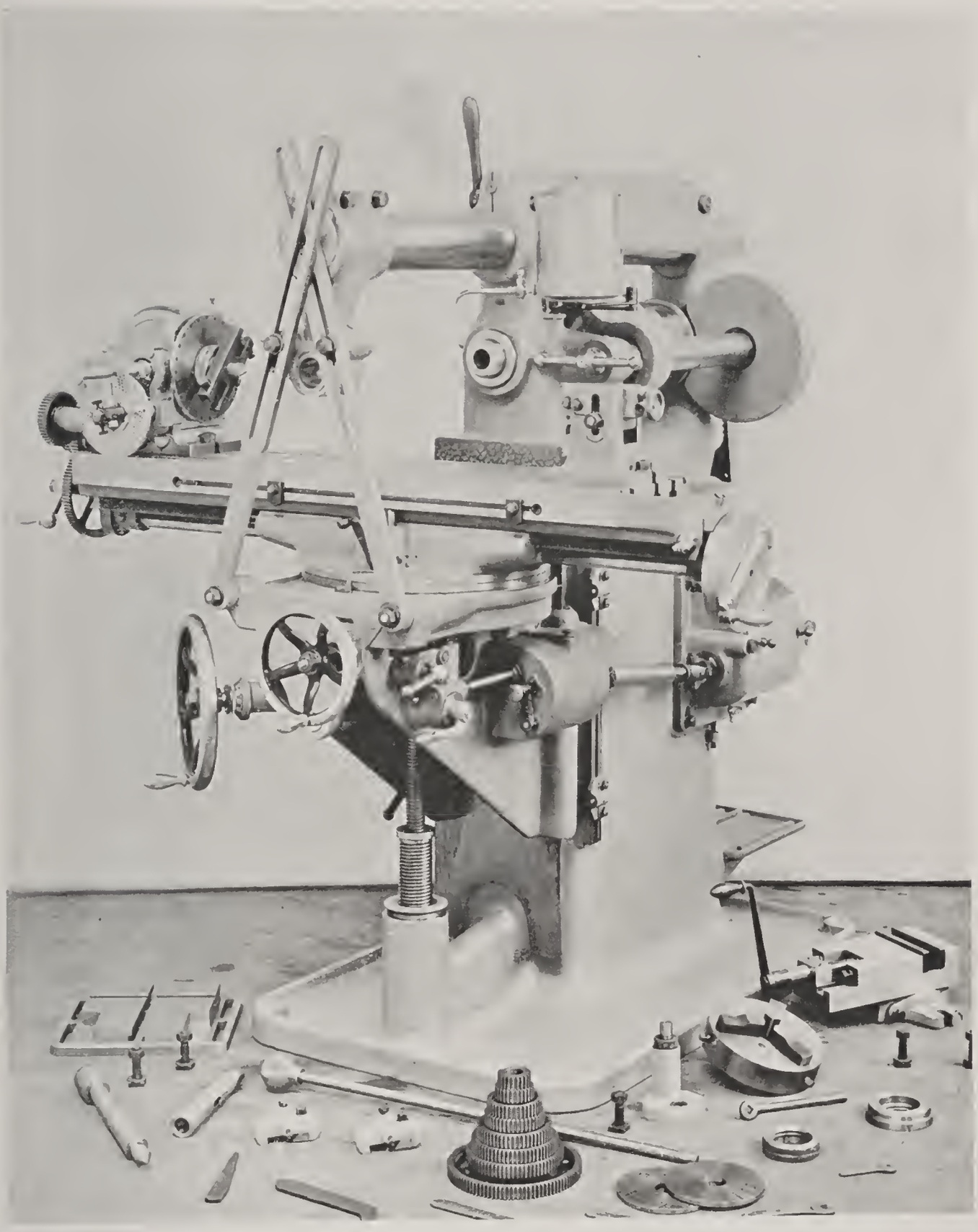

FIG. 84.

NO. 3 UNIVERSAL MILLING MACHINE.

Brown and Sharpe Manufacturing Co., Providence, R.I.

Spindle Speeds.

Back Gears. In.			Back Gears. Out.		
Counter Reverse.			Counter Reverse.		
Slow.		Fast.	Slow.		Fast.
16	17	19	79	88	96
24	26	29	118	131	144
35	39	43	175	194	212
53	58	64	262	290	318

Table Feeds.

Feeds per Revolution of Spindle.					Levers.	
					Left.	Right.
·003	·004	·005	·006	·007	Up	Up
·017	·014	·012	·010	·008	Up	Down
·021	·026	·031	·039	·047	Down	Up
·120	·100	·083	·067	·055	Down	Down

In other words, the modern operator has at his control, by the shifting of one or two levers or possibly a belt, 24 speeds and 20 feeds, and has small excuse for not using the ones best suited to the work in hand.

The feed motions are transmitted from the gear case through the Hooke's joint to another gear case on the saddle, where is usually located the starting lever by which the feed can be reversed or started in either direction. The further transmission to the two or three screws which operate the table and its supports is necessarily rather complicated, especially in the universal machines, where the table feed must be driven from the centre of the swivel. No attempt

will be made here to describe these in detail, but attention will be called to results. On most machines of the No. 2 size or smaller, only the longitudinal and transverse feeds are automatic, but the larger sizes have also a power feed for the elevating screw. The hand-wheels or cranks controlling the various feeds directly, are fitted with clutches which can be disengaged when the wheel is not in use and thus prevent danger of the adjustments being disturbed. The hubs of all hand-wheels have graduated dials to facilitate accurate adjustment. Trip motions are provided for the table feed, operated by dogs on its front edge. There is a quick return for the table with a hand-wheel, located preferably at the right end.

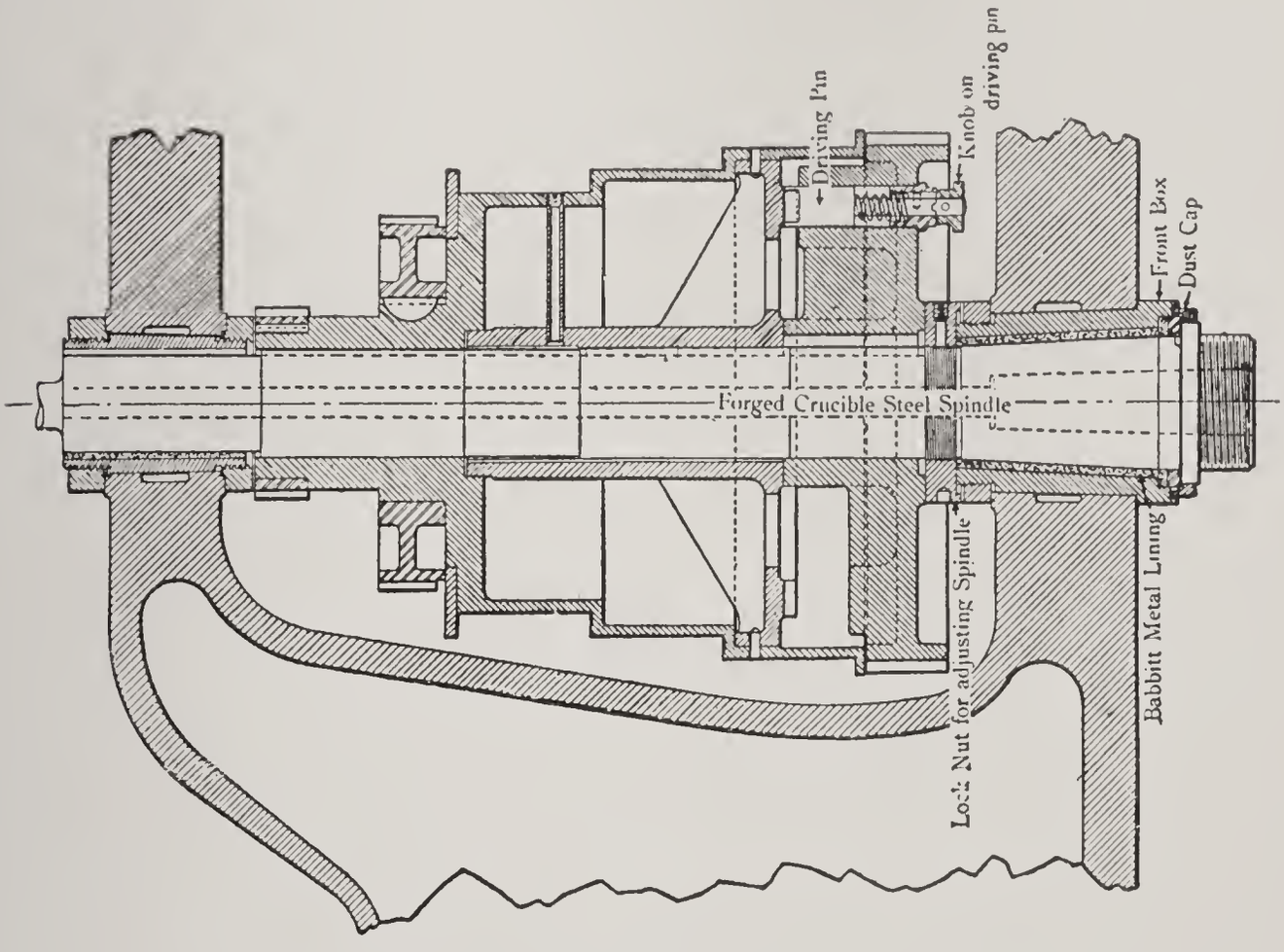

FIG. 85.

DETAILS OF SPINDLE.

Cincinnati Milling Machine Co.

118. Attachments.

The milling machine, and more especially the universal machine, is to a large extent dependent upon the various

special attachments which hold and control the work. When a plain machine is at work on plain pieces, little is needed more than the usual chuck or vice, but when it is necessary to cut flutes or spirals upon cylindrical or conical pieces, more elaborate devices must be had. The remarkable record of the milling machine is due as much to improvements in the table attachments as to those in the machine itself.

119. The Universal Head.

The so-called universal head can be used on all machines as a dividing or indexing head, while on universal machines it may be used for cutting spirals by being geared to the lead screw of the table.

It may be well to state here that the term spiral as used by American manufacturers means a helix and not a flat spiral.

To illustrate one form of the universal head, reference is made to Fig. 86, which shows the details of such a head as used on the Cincinnati Milling Machines. It is shown clamped on the table of a universal machine, so that its spindle is parallel to the lead screw. The head and table may then be swivelled to such an angle with the spindle of the machine as to bring the cutter tangent to the spiral desired. The head spindle is shown geared to the lead screw by change gears to give the proper rotation and translation for the spiral. The indexing or dividing mechanism turns the spindle by means of the worm and wheel shown in the two latter views. The worm turns in an oil-bath, and can be disengaged when not wanted by dropping down one bearing. When plain or direct indexing is to be done, the worm is disengaged and an index plate on the front end of spindle is used.

For bevel or taper work the entire head can be swivelled about a horizontal axis, perpendicular to the spindle, without disturbing the relations of the driving gears or indexing

mechanism. The trunnions on which it turns are nearly the full size of the head and can be clamped by the circular straps embracing them. The head can be turned from 10 degrees below the horizontal to 50 degrees beyond the vertical, or 150 degrees in all. The centre of the tailstock can be raised or lowered, and can be swivelled 10 degrees above or below the horizontal to accommodate taper work.

The Brown and Sharpe style of head may be seen in position on the machine shown in Fig. 84. It possesses adjustments and movements similar to those just described. Special heads are sometimes designed for spiral milling without the swivelling attachment and with a simpler indexing mechanism than is found in the universal head.

On the other hand, indexing heads are made for use on plain milling machines, without any automatic driving mechanism and without any swivel. These are suitable and convenient for straight work. Briefly, a head may be capable of cutting straight flutes on cylinders, of cutting spirals on cylinders, or of cutting either straight or spiral flutes on either cylindrical or conical surfaces.

120. Chucks and Vices.

The vice for holding work which cannot be placed on centres may have one or more degrees of freedom. The plain vice, similar to that used on a shaper, has no adjustment, except opening and closing on the work. The swivel-vice, as its name implies, allows the work to rotate in a horizontal plane, the swivel being graduated to degrees. A circular milling attachment can be fastened to the table of any machine, and consists of a circular platen furnished with slots for bolting on the work, and capable of being rotated by a worm and wheel. An automatic rotary feed can be attached if desired, but the hand-wheel is generally used. The circumference of the platen is graduated, and it may be locked in any desired position. This device is particularly

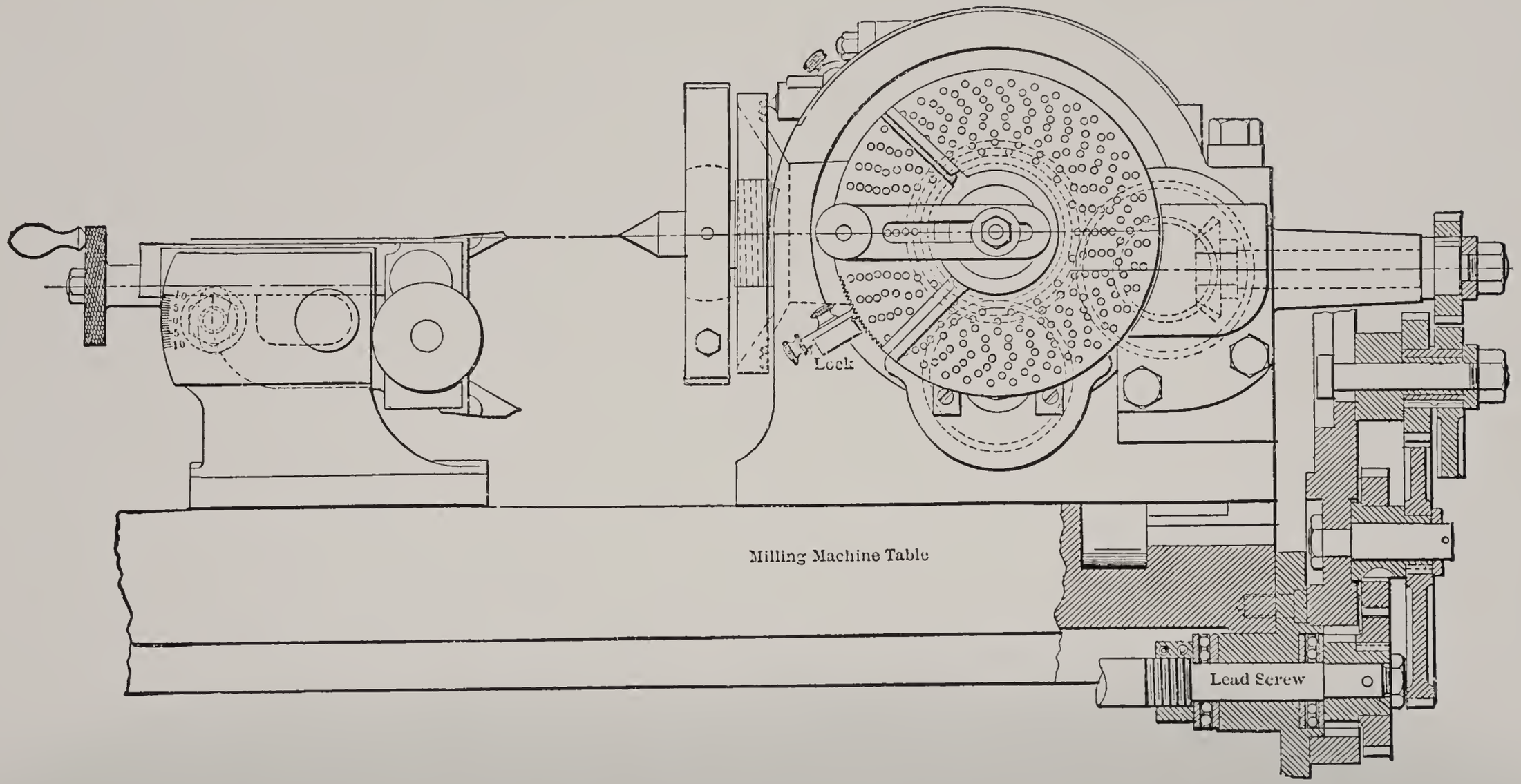

FIG. 86*a*.

NEW UNIVERSAL DIVIDING HEAD.

Cincinnati Milling Machine Co.

convenient when used in connection with a vertical milling attachment.

121. Spindle Attachments.

Arbors are furnished in different lengths and diameters. They fit a standard taper socket in the end of the spindle, and are forced out either by a nut on the shank of arbor or by a screwed rod in the hollow spindle. Collets of various

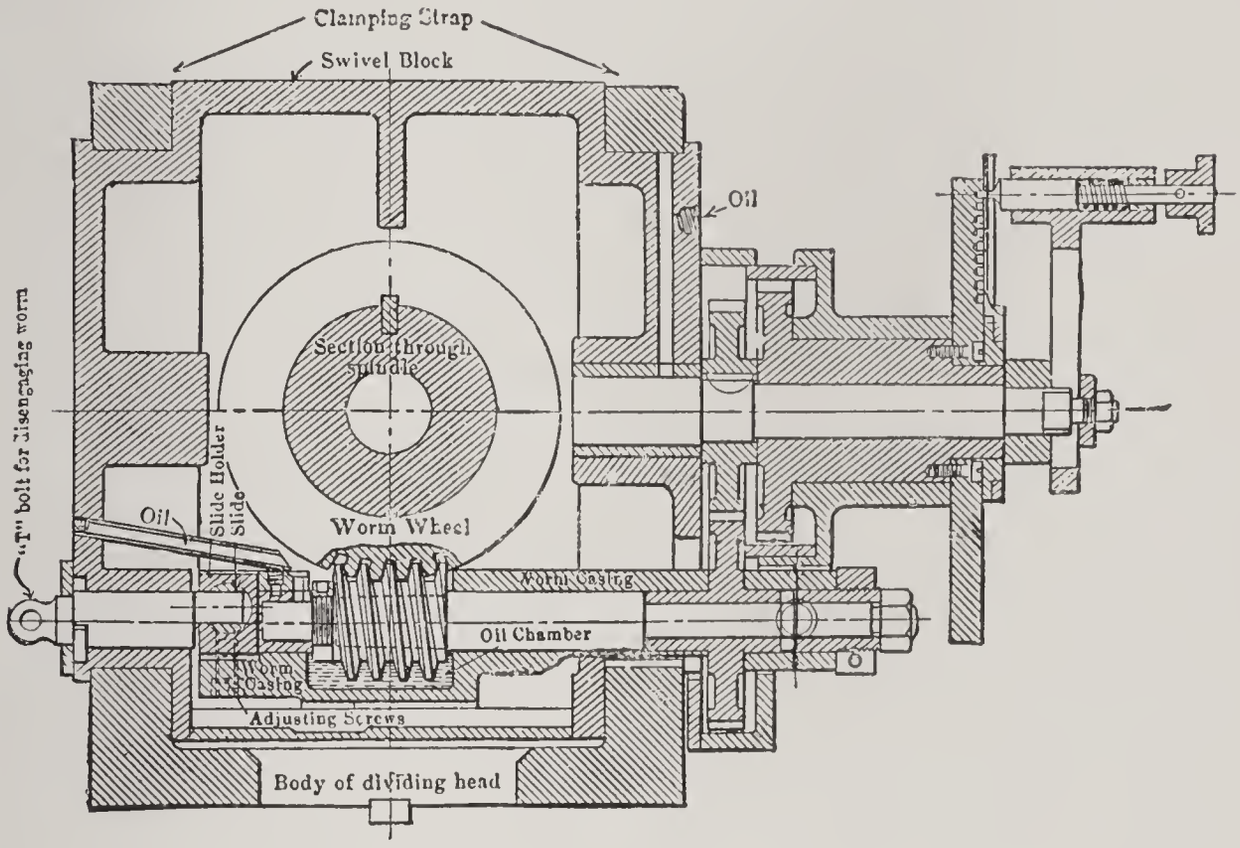

Fig. 86*b*.

shapes and sizes can be fitted to the spindle for holding small mills and end-cutters. Several attachments have been brought out by various manufacturers for performing special operations other than ordinary milling, such as vertical milling, slotting, and cam-cutting.

While these attachments will undoubtedly do what is claimed for them, they will not do it as well as a special machine, and can only be tolerated in a small shop for intermittent jobs. The manufacturer who wishes to do profiling or slotting or cam-cutting in any quantity had better buy machines better adapted to these special operations than the ordinary milling machine.

Such attachments are usually bolted to the face of the headstock near the spindle, and are driven by a special arbor. The vertical milling attachment consists of a vertical spindle, running in adjustable bearings and driven through mitre gears from the spindle. It is capable of being swivelled in a vertical plane to any angle. The attachment is steadied by a special support on the overhanging arm. The slotting attachment is supported in a similar manner, and carries a slotted crank and pitman for driving a vertical slotting head.

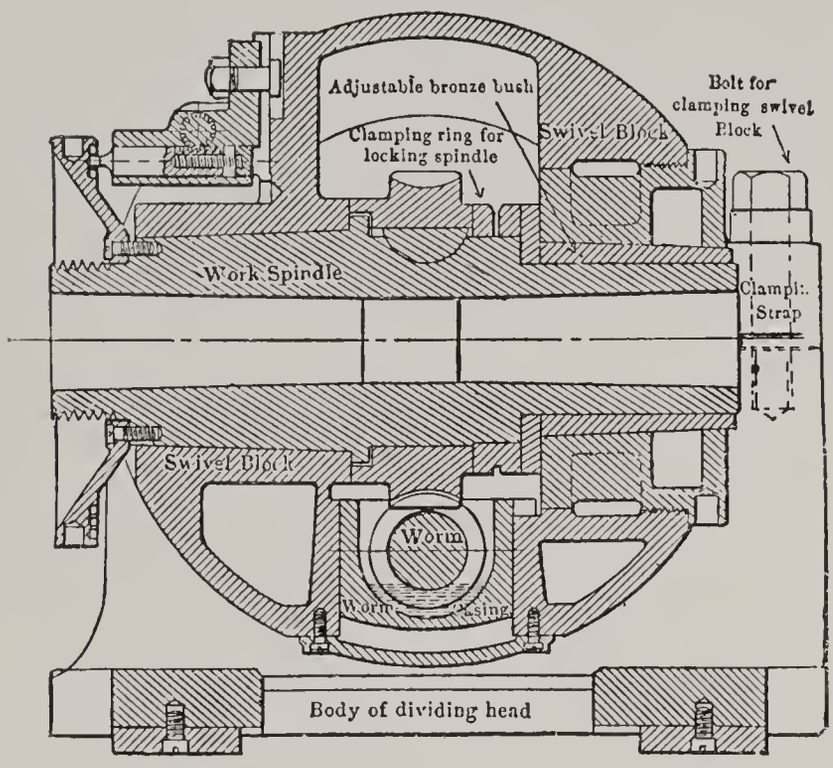

FIG. 86c.

The rack-cutting attachment, on the other hand, drives a horizontal arbor at right angles to the spindle in such a way as to cut racks which lie lengthwise on the table and thereby cut them of any length. Such a device, used in connection with the universal machine, makes it possible to cut wide spirals whose angle is greater than 45 degrees.

122. High-Speed Milling.

Most manufacturers recommend cutting speeds for the milling machines of 20, 40, and 60 feet per minute when milling steel, cast iron, and brass respectively. There is no accepted standard for feed of the table in inches per minute, and the feed per revolution of spindle varies from 3-thousandths to as many tenths of an inch. Perhaps from 3 to 6 inches per minute may be considered ordinary table speeds for cast

iron. The above speeds and feeds are for ordinary carbon-steel milling cutters.

It is undoubtedly true that better results can be obtained by using coarser feeds than usual; in other words, by having as thick a chip as possible per tooth of cutter. Increasing the surface speed of cutter will shorten its life; but increasing the table feed will not usually injure the cutter, although it may stall the machine. Table feeds of from 10 to 15 inches a minute have been successfully used of late. The following table sums up some results published by the Cincinnati Milling Machine Co., and gives a good idea of advanced practice in the United States:—

Kind of Milling.	Material Cut.	Width of Cut. Inches.	Depth of Cut. Inches.	Speed of Cutter. Feet per Minute.	Table Feed. Inches.	
					Per Revolution of Spindle.	Per Minute.
Slab, . .	Cast iron	$8\frac{1}{4}$	$\frac{1}{8}$	40	·252	8·50
Slab, . .	,, ,,	$6\frac{1}{2}$	$\frac{3}{32}$	40	·168	5·75
Face, . .	,, ,,	$5\frac{7}{8}$	$\frac{1}{8}$	40	·138	2·63
Face— Finishing,	,, ,,	$4\frac{3}{16}$	...	60	·252	13·00
Gang, . .	,, ,,	$9\frac{1}{4}$	$\frac{1}{8}$	40	·075	2·32
Gang— Finishing,	,, ,,	...	...	40	·100	1·25
Gang, . .	,, ,,	$7\frac{5}{8}$	$\frac{3}{32}$	47	·075	3·00
Spiral, .	Tool steel	$\frac{3}{4}$ top	$\frac{1}{2}$	...	·025	0·75
Spiral— Finishing,	,, ,,	...	...	...	·036	1·08
Slab, . .	,, ,,	5	$\frac{1}{32}$	44	·050	2·8
Spline, .	Mch. ,,	$4 \times \frac{1}{4}$	$\frac{1}{8}$	40	·075	4·5

123. Lincoln Milling Machines.

By the term Lincoln machine is meant one in which there are two housings or supports for the arbor, on which the latter can be adjusted vertically, the table having no

vertical adjustment. Fig. 87 shows the principal characteristics of this class of machine. It is not so universal in its adaptations as the machines just described, but is a convenient machine for duplicating small pieces in large quantities. It is compact and rigid, and is so arranged as to be convenient for the operator. One housing is broad and stiff, carrying the driving spindle, while the other is more slender, merely forming a support for the outer end of arbor. These are joined at the top by an arm which carries a third intermediate support for the arbor.

It is evident from this construction that the machine is particularly firm and stiff. The spindle head is intended to be locked in position when the machine is running. Fig. 88 illustrates a large duplex machine of this same class, or rather a cross between the Lincoln machine and the planer type. This milling machine has revolving spindles on each housing, which are independent of each other. The housings can be adjusted independently on the bed, and the heads adjusted independently on the housings. For greater rigidity the bed is extended to support the platen, much the same as in a planing machine. The result is a massive, strong machine, well adapted for heavy roughing work on forgings or castings.

The machine can be used for slabbing cuts, or by mounting face plates with inserted teeth on the spindles it becomes a rotary planer.

124. The Manufacturing Machine.

This term has come to mean a small machine, especially adapted for making large quantities of some particular piece, and is generally used for a few operations many times repeated.

The spindle head, in this case, is pivoted to a standard at the rear, and can be moved up and down in a circular arc. It is guided by segments on two standards in front, and can be clamped to these at any desired position. The spindle is

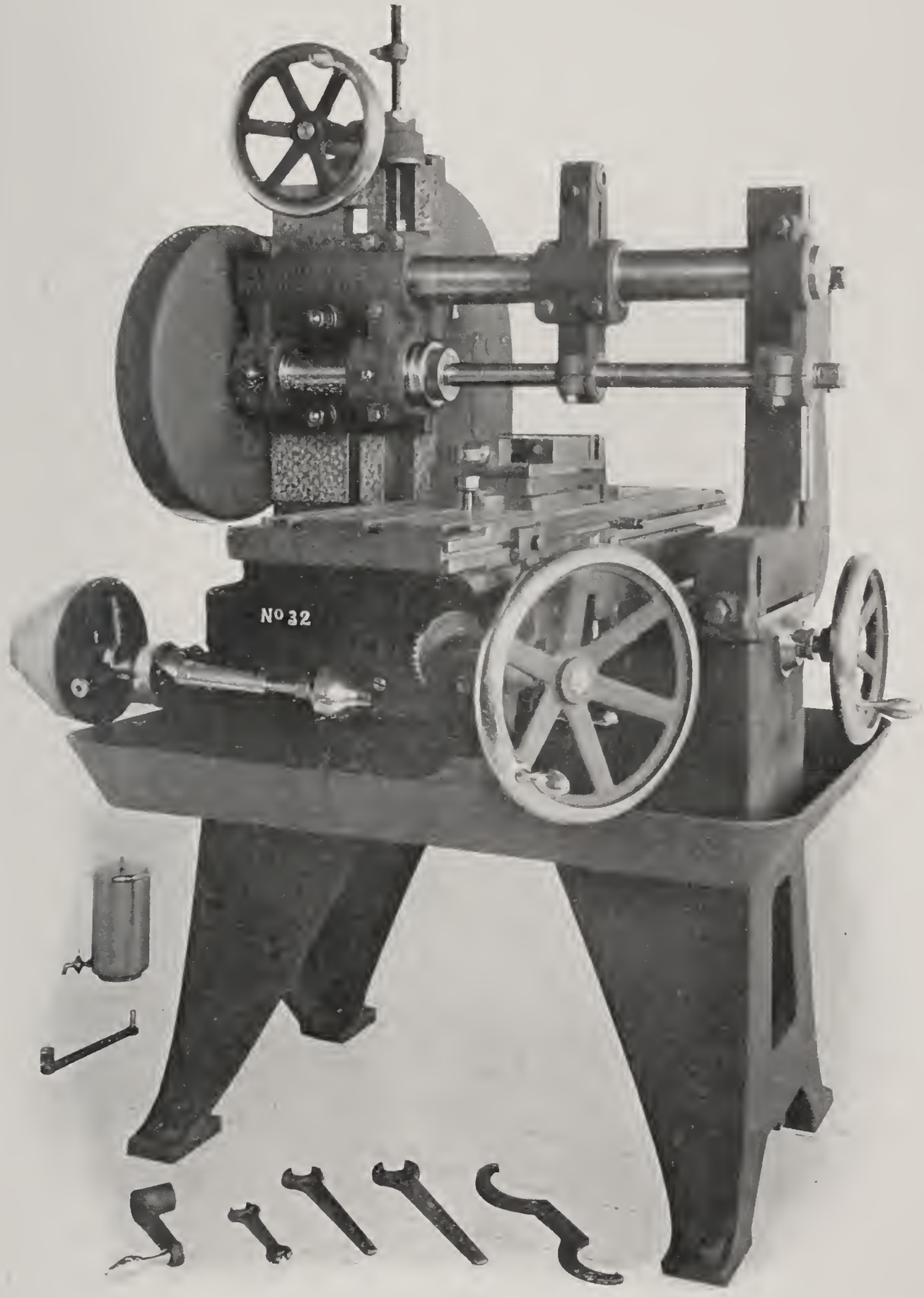

Fig. 87.

LINCOLN MILLING MACHINE.

The Kempsmith Manufacturing Co., Milwaukee, Wis.

driven by gearing from the pulley shaft, the axis of the latter coinciding with the pivots on which the head swings. The overhanging arm is similar to that on any plain milling machine, is supported by an outside brace or yoke, and carries the usual arbor support. The table slides in ways planed

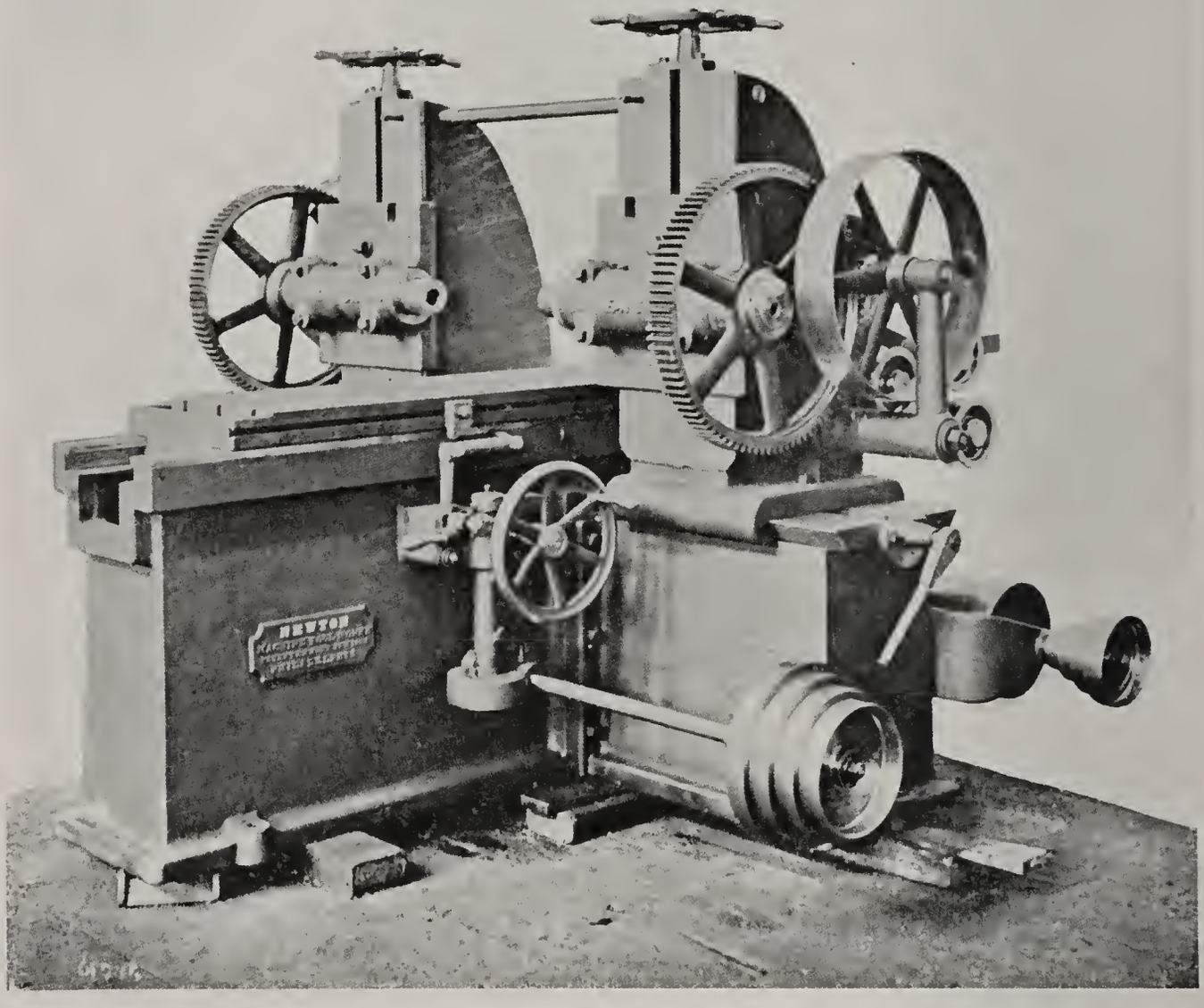

FIG. 88.

DUPLEX MILLING MACHINE.

Newton Machine Tool Co., Philadelphia, Pa.

directly in the bed, and has, consequently, no transverse motion.

The feed for the table is automatic, and is driven by gears from the pulley shaft, three changes being available.

125. Profiling Machines.

If it becomes necessary to outline the edges of a flat piece, or to cut grooves or recesses of any shape in the face of such a piece, the vertical spindle is much more convenient than the horizontal, because it permits the work to be clamped flat on the table where all the outlines can be clearly seen. The vertical spindle machine is frequently called a profiling machine, in view of the uses just mentioned.

The characteristics of such a machine are high speed and careful alignment of spindle. Such work as has been described must be done by an end-cutting mill, or at least by one with a free end, and this fact makes it all the more necessary that the bearings of the spindle should be carefully adjusted. Fig. 89 illustrates a two-spindle profiling machine, and Fig. 90 the details of the spindle bearings and gearing.

The spindle is hollow, with a rod for holding and for ejecting the mill. The lower bearing is conical, with a lock nut above to draw back the spindle, and a rotating washer below to take the end thrust. The upper bearing is cylindrical, and being split, is adjusted for wear by the lock nuts shown.

The spiral gear at the centre, which gives the motion, runs in bearings of its own independent of the spindle, so that the latter is relieved from all side pressure. This construction also permits adjustment of the gears to take up back-lash, without disturbing the alignment of the spindle. The ball-thrust bearings shown take the end pressure, due to the action of the spiral gear. The other gear is supported in a similar manner, and both gears run in a tight casing filled with lubricant. This construction relieves both spindle and shaft of all side pressure, and permits the use of high speeds. It is possible, with the machine shown, to run at a speed of 1200 revolutions per minute.

The particular machine illustrated in Fig. 89 has two

spindles, the intention being to use a roughing cutter in one,

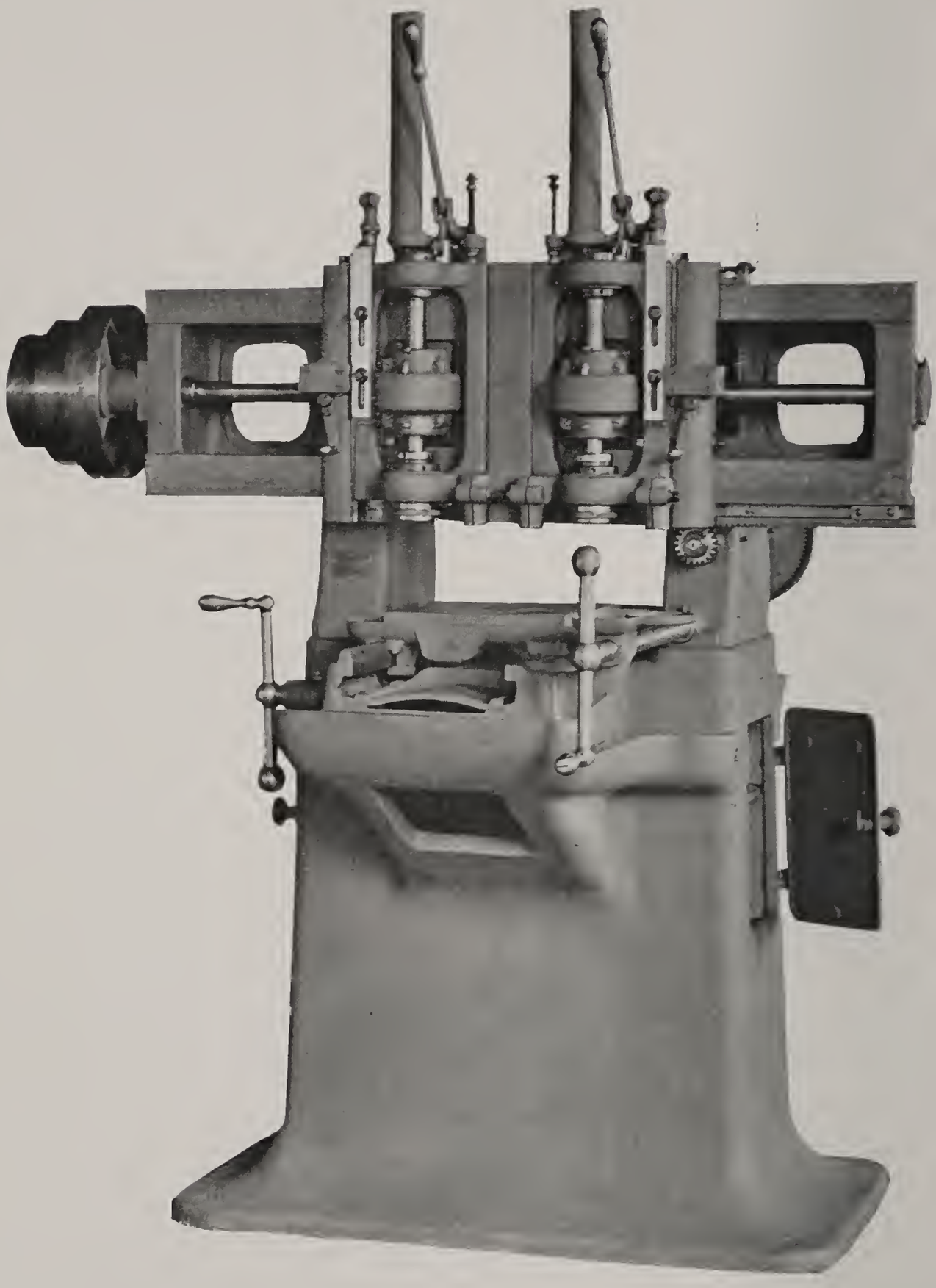

FIG. 89.

TWO-SPINDLE PROFILING MACHINE.

The Pratt and Whitney Co., Hartford, Conn.

and a finishing cutter in the other. This will permit finishing the work without resetting and without changing the cutter.

Each head is adjustable vertically in the saddle, and is held up by a heavy spring. Micrometer adjustments and suitable stops make it possible to gauge the exact depth desired in work like die-sinking.

The saddle can be fed along the cross-rail by means of the rack and pinion shown, controlled by the large crank at the right of the table. The table is fed transversely in a similar manner by the left-hand crank. The operator can thus manipulate the machine readily from his position in front.

Since lost motion of any kind is particularly objectionable in this kind of work, provision has been made to eliminate it by using double racks and pinions on both table and cross-rail. The two parts are mutually adjustable, which has the effect of widening the tooth and taking up all back-lash.

The other details of this machine may be seen from the cut.

126. Vertical Milling Machines.

Fig. 91 shows a vertical machine less restricted in its operation than the one just described. In fact, this machine is the same as the ordinary plain column milling machine, with this one exception, that the spindle is now vertical.

An examination of the illustration will show the details of column, knee and table, to be almost identical with those in the horizontal machine. No particular attention need be given these details, but the peculiar characteristics of the vertical type will be noticed.

The spindle is carried on a head which has a slight vertical movement, controlled by a spring and by the foot lever shown. This leaves the hands of the operator free to manipulate the table. To relieve the belt pull on the spindle and preserve its alignment an auxiliary support is bolted to the top of the frame. This is open on the front, and can be adjusted at the back to take up any wear that may occur. A rotary milling attachment is shown in the illustration, bolted to the table and connected with the automatic feed by

gearing. The machine is intended for use with small cutters at high speeds. By using a small pulley on the spindle, speeds as high as 4000 revolutions per minute can be obtained.

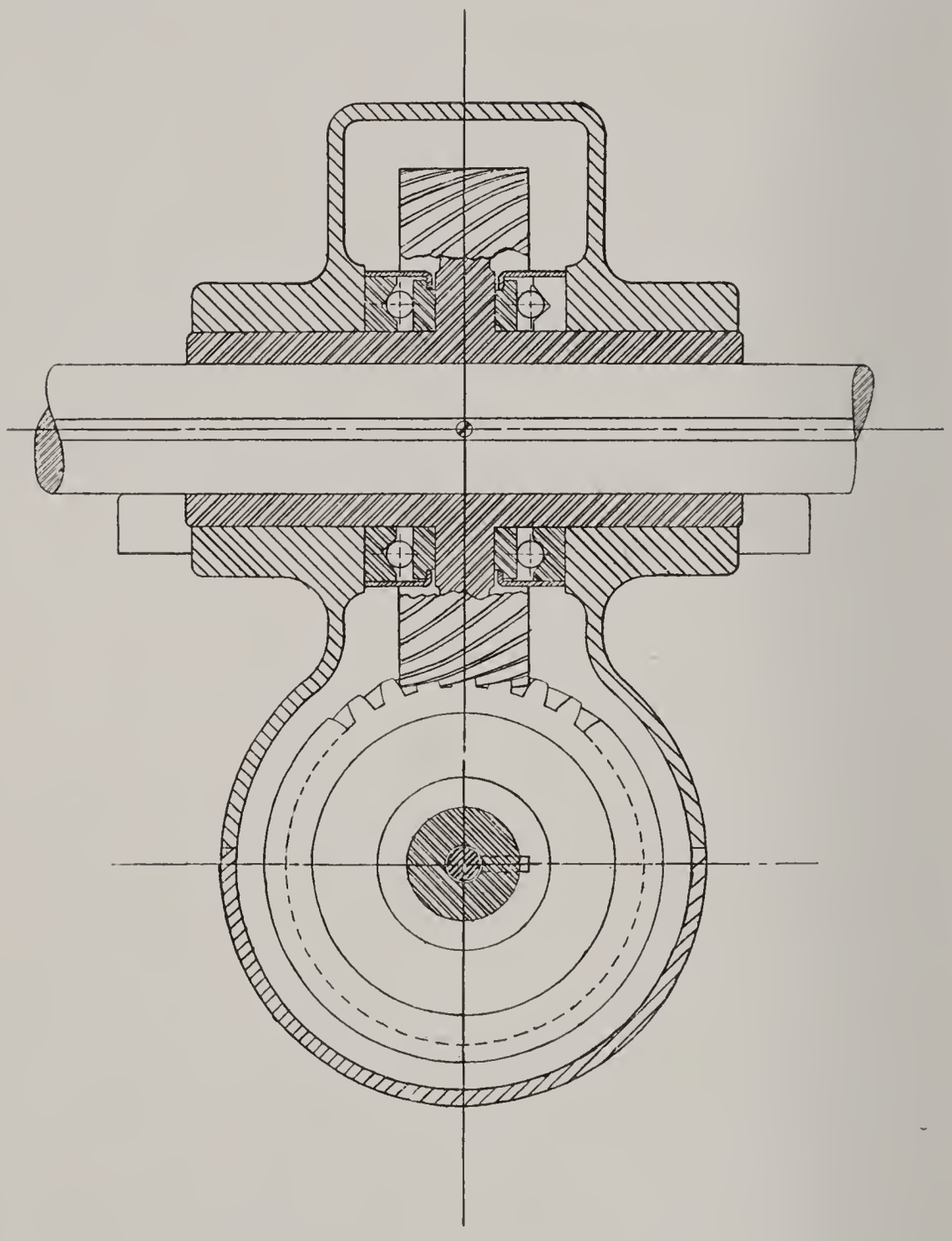

FIG. 90.

DETAIL OF SPINDLE.

The Pratt and Whitney Co., Hartford, Conn.

While more universally adaptable than the profiling machine, the vertical milling machine is not so convenient as the former for hand manipulation, since it has more lost motion in the joints and does not have as handy an arrangement of feed cranks. Some of the small milling machines are

furnished with rack feed for the table, as better for rapid work.

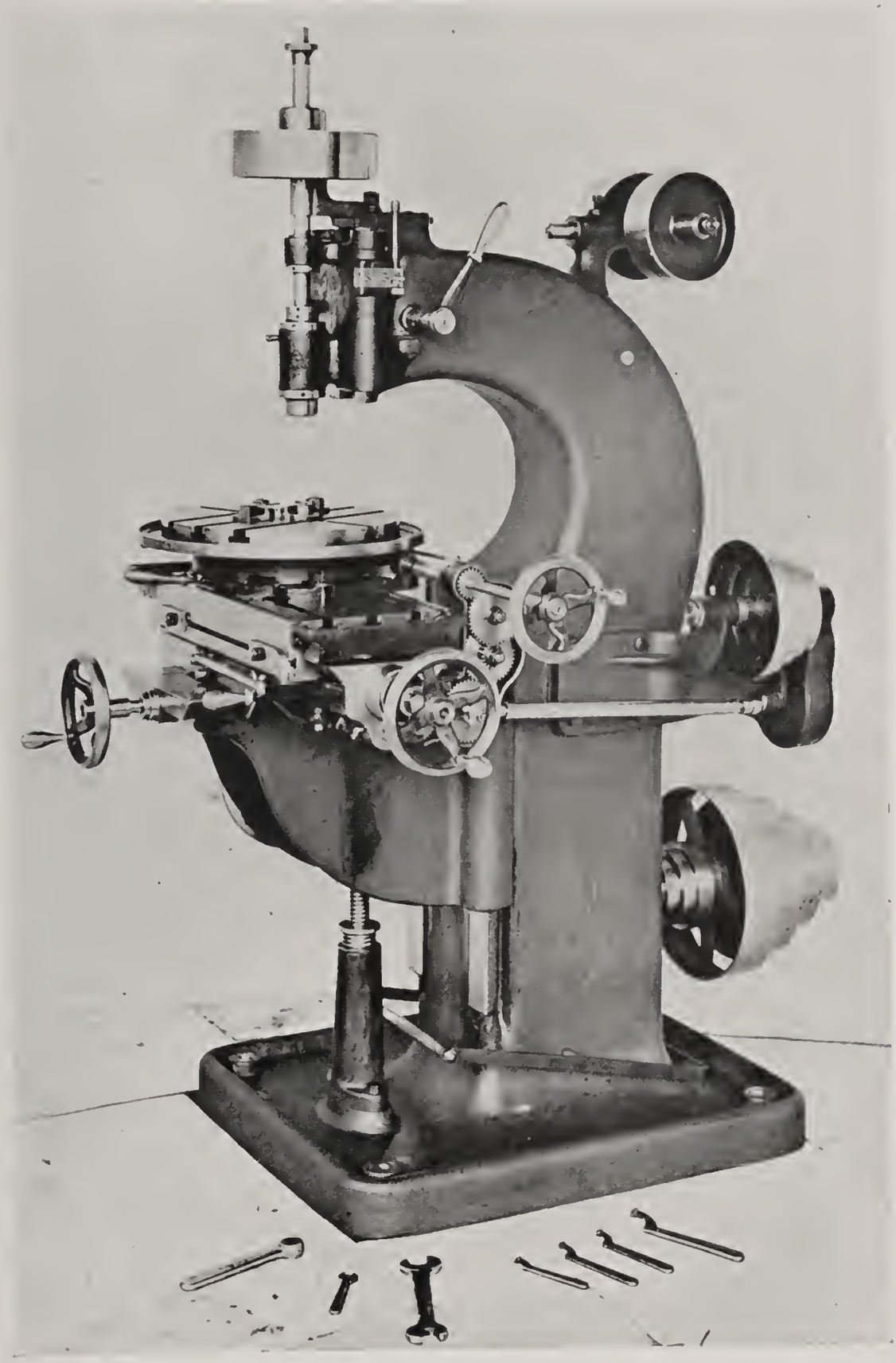

Fig. 91.

VERTICAL MILLING MACHINE.

The Becker-Brainard Milling Machine Co., Hyde Park, Mass.

In Fig. 92 is shown one of the larger sizes of vertical machine adapted for heavy work. The cabinet is massive

and supports the table directly, while the head is mounted on a circular column cast to the rear of the cabinet. A novel adjustment of the head is obtained by making the column telescopic. The inner column carrying the head is raised or lowered by the wheel shown back of the table at the right. There is also a micrometer adjustment of the spindle in the head, operated by the hand-wheel shown. The spindle is driven by a chain inside the casting from the vertical shaft shown in the cut, and is provided with special devices for holding positively large or small cutters. The whole head is of a good design to ensure strength and rigidity.

The table is mounted on a saddle, and that in turn on flat ways cast to the bed. Both longitudinal and transverse feeds are controlled by hand-wheels at the front of the machine. Both feeds are automatic, and can be varied by a gear-box similar to that used on the horizontal machine.

The machine shown in the illustration is back-geared, has 12 changes of speed, and 40 changes of feed, varying from ·002 inch to 0·6 inch per revolution of spindle.

A comparison of these machines with some of the boring and drilling machinery already described will disclose a marked resemblance. A drilling machine with automatic feeds to the table is very near to being a milling machine, and a vertical milling machine with a circular milling attachment is very like a boring mill. Perhaps the most marked characteristic of the milling machine is the rigidity and comparative restraint of its spindle. As a rule, the milling spindle, like the lathe spindle, revolves steadily in its bearings, and the work must come to it.

127. Power and Capacity.

Some data with regard to the limiting speeds and feeds of milling machines have been given in a previous paragraph, but reliable figures for the amount of power needed are hard to find. Such experiments as have been made with the aid

of dynamometers, show that the ordinary spiral milling cutter

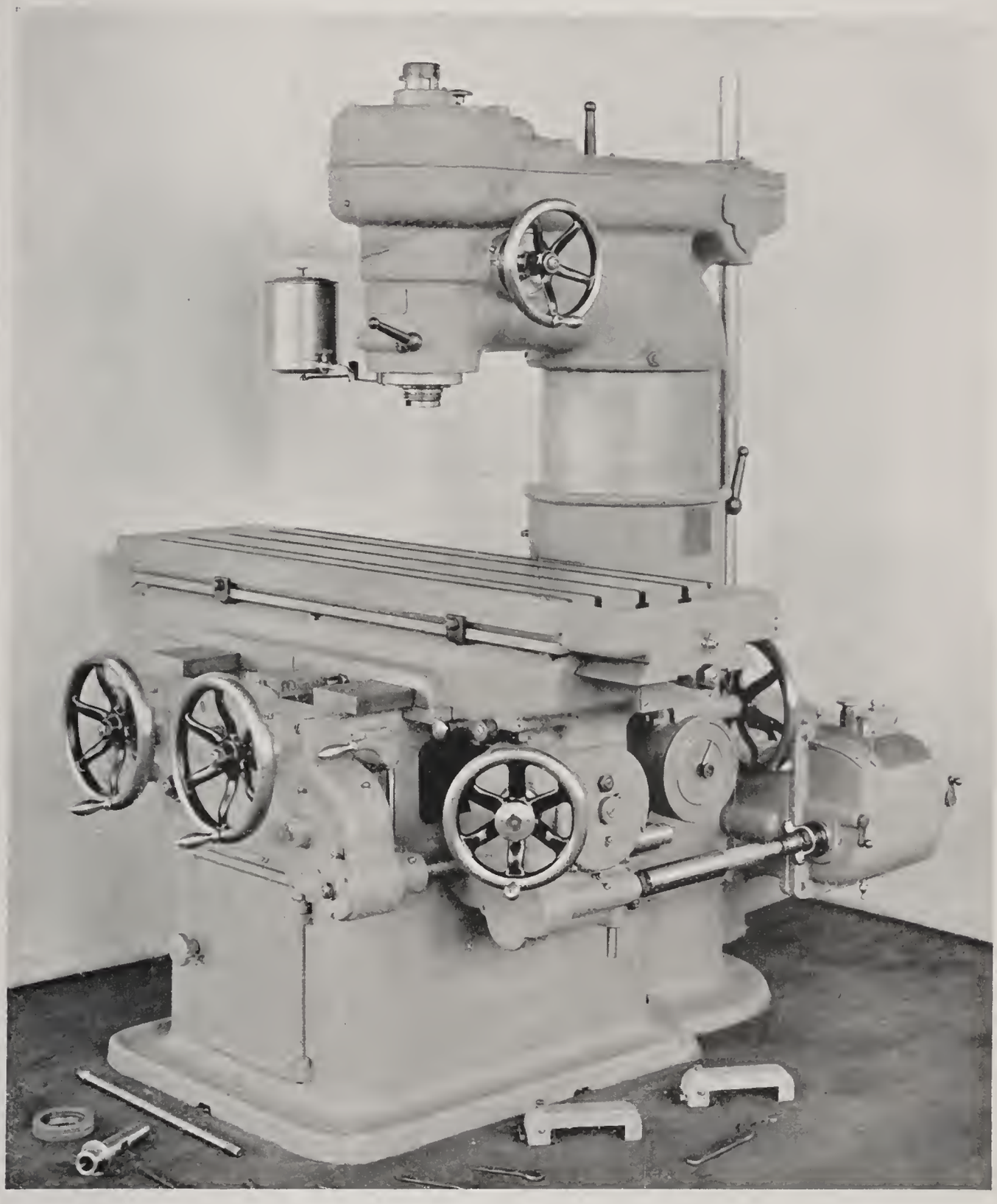

FIG. 92.

NO. 5 VERTICAL SPINDLE MILLING MACHINE.

Brown and Sharpe Manufacturing Co., Providence, R.I.

consumes more power per cubic inch of metal removed than the lathe of the planer.

This is doubtless generally true since the shape of tooth is

not so favourable for the removal of chips without friction as that of the diamond point.

Professor Flather reports the consumption of ·14 h.p. per pound of cast iron per hour, which is three or four times as much as would be required by a good engine lathe. The writer once found in testing a large gap lathe values ranging from ·12 to ·16 h.p. per pound per hour when using an inside tool, a somewhat analogous case.

Probably large machines employing inserted cutters would show much lower values. The Hess Machine guarantees with one of its heavy milling machines and special cutters a roughing cut on cast iron 42 inches wide, $\frac{1}{2}$-inch deep, and 10 inches feed per minute, making 210 cubic inches, or 54 pounds of metal per minute.

Mention is also made of cutting 36 inches wide, $\frac{1}{2}$-inch deep, and 8 feet long in 30 minutes or 57 cubic inches per minute.

The following sizes of motors were recommended for milling machines to be used in a railway shop :—

		Motor H.P.
Heavy slab,	milling machine,	15
Heavy vertical,	,, ,,	10
Smaller vertical,	,, ,,	7·5
Heavy universal,	,, ,,	5
Plain horizontal,	,, ,, No. $1\frac{1}{2}$	4
Small plain,	,, ,,	2·5
Small universal,	,, ,, No. 3	1

CHAPTER VIII

GEAR CUTTING

128. Gear Cutting in General.

At the present time it is not necessary to make any arguments for the use of cut gears in preference to those in which the teeth are cast. In all improved machinery cut gears are now the rule, and the only question at issue is how to cut them the most accurately and cheaply.

Gear-cutting machines may be classified as follows: (1) plain machines indexed by hand; (2) automatic gear cutters of the milling machine class; (3) gear shapers where the tooth outline is generated automatically; (4) gear planers used particularly for bevel wheels. To this list may perhaps be added the thread milling machine, considering the screw thread as the tooth of a spiral gear.

The arguments for the use of one or the other of these machines will be discussed later. The plain gear-cutter with a hand index needs no description, since it is merely a plain milling machine adapted for this particular purpose.

These machines can be run in gangs and several of them managed by one attendant. Where stock gears are made in considerable quantities, it is well to have a separate machine for each size and kind of gear, the index wheel containing just the same number of holes as the wheel has teeth. This makes it possible to cut teeth at random around the wheel and avoid uneven heating. This is especially desirable in large gears. It is a well-known fact that stopping a machine

which is cutting teeth in regular rotation around the wheel will produce a jog or irregularity on account of the heating and cooling of the metal.

One man or boy can attend a large number of machines arranged as just described, and turn out nearly, if not quite as much work as with the automatic machines.

129. Automatic Machines.

Where a large variety of wheels are to be cut, especially if they be of small size, the automatic machine is almost a necessity for economical production.

An automatic gear-cutter means one which will perform all the operations of cutting and indexing automatically, when once the blank is put in place, the cutter adjusted and the machine started. These may be had in all sizes ranging from the smallest machine which cuts pinion teeth on a rod $\frac{1}{8}$ inch in diameter, to the largest machine intended for gears 8 or 9 feet in diameter.

In discussing these different machines it will be necessary to consider each by itself, since there is not the same family resemblance as among lathes or planers. The Slate automatic machine intended for small gears from $\frac{1}{8}$ inch to 4 inches in diameter and cutting teeth from 50 pitch to 16 pitch, has the arrangement of cutter spindle and work spindle the same as in the ordinary plain milling machine, the former being above the latter. In fact the machine can be used for making reamers and other circular cutters as well as for gears.

The work can be held in a chuck or on centres according to its character.

The index head is firmly locked in position while the tooth is being cut and is then turned automatically to the next position.

The feed of the table which carries the work is operated by a cam at the right end which gives a slow advance and a

quick return. The cam works against a roll on the slotted lever or crank, and this in turn is connected with the table by

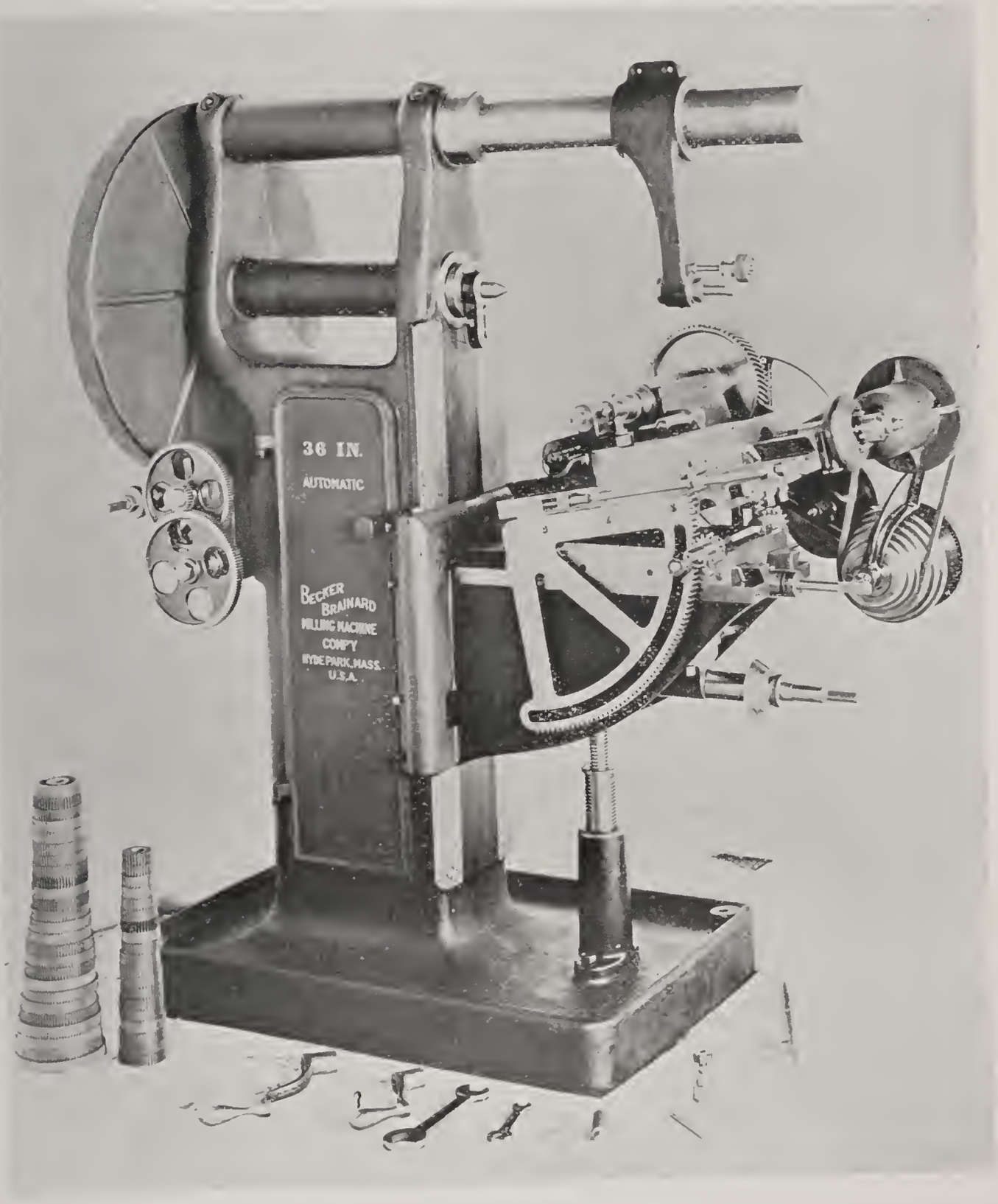

FIG. 93.

36-INCH AUTOMATIC GEAR CUTTER.

The Becker-Brainard Milling Machine Co., Hyde Park, Mass.

an adjustable rod. It is thus possible to use the same cam for different lengths of stroke, and by varying the radius of

crank any desired stroke can be obtained. After this has been done, the length of rod is adjusted to bring the work in the right relation to cutter. The cutter can be thus arranged to just clear the work at each end of stroke and time be saved. The return of the table is effected either by a coiled spring or by a weight.

The feed is thrown out of gear automatically at the completion of the work. The operations of reversing and indexing the machine consume from one to five seconds' time according to the speed at which the machine is running.

When larger gears are to be cut the work and the dividing wheel are usually mounted upon the main spindle of the machine while the cutter is carried upon the table, thus reversing the arrangement just described.

Fig. 93 shows a machine of this style adapted for cutting gears up to 18 inches in diameter.

The general appearance is still that of the milling machine with a pillar support. The overhanging arm is present, being used to support the outer end of the work mandrel. At the rear end of this mandrel is located the index or dividing wheel, and this is operated automatically by a train of gears.

The table which carries the cutting mechanism is universal; it can be raised and lowered to give the right depth of cut by a screw with micrometer attachment; it can be tipped vertically from 0 to 90 degrees for cutting bevel gears and can be set at any angle horizontally for cutting spirals. The automatic feed is parallel to the spindle of the machine and in the plane of the cutter.

Return is made at a speed forty times that of the advance without any change of direction of the belting and pulleys.

The feed can, however, be disconnected by a clutch and the machine be adjusted or fed by hand. There is also an arrangement by which the wheel to be cut may be turned one way or the other without disturbing the indexing mechanism, as is necessary in cutting bevel gears when a change is to be made from one side of the tooth to the other.

This particular machine is intended to cut gears up to 18

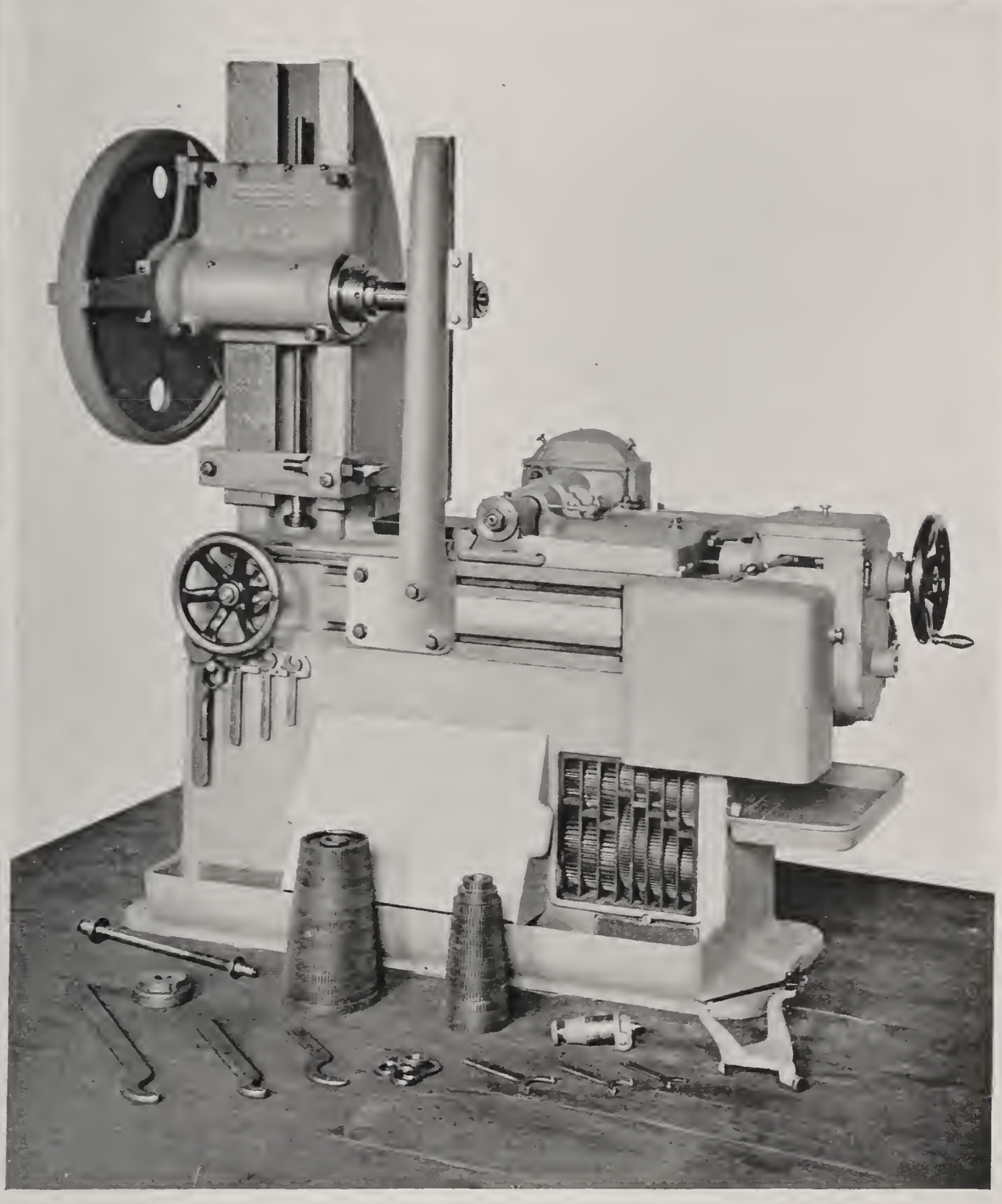

FIG. 94.

48-INCH AUTOMATIC GEAR CUTTER.

The Brown and Sharpe Manufacturing Co., Providence, R.I.

inches diameter, 4 inches face, and 6 pitch, and has a rate of feed of from 2 to 7 inches per minute.

The need of greater rigidity in the frame where large gears are to be cut has led to a decided modification in the design, as may be seen by reference to Fig. 94. This machine is designed to cut gears up to 48 inches diameter and 9 inches face, with 4 pitch teeth. In general appearance it resembles a horizontal boring mill rather than a milling machine, its principal characteristic being a massive cabinet bed for the support of the table. A strongly braced upright at the left of the frame carries a slide on which is mounted the mandrel for the work. This slide can be adjusted vertically by an elevating screw resting on ball bearings. A graduated dial gives the adjustments in thousandths of an inch. The large index wheel at the rear end of the spindle is automatic in its action, but can be disengaged at any time and turned by hand. At the end of the cut the return of the carriage, the release of the locking disk, the turn of the index wheel, and the re-locking, are accomplished almost instantaneously and without shock or jar.

This mechanism is driven by a separate belt so that the speed is independent of that of the cutter.

The cutting mechanism is carried on a carriage or saddle having large bearing surfaces on top of the bed. The cutter itself is driven by worm gearing and has six changes of speed. As may be seen from the figure, the cutter arbor is supported at the outer end, as is also the work spindle. An abutment is provided to hold the work firmly against the pressure of the cutter.

The advance feed of the carriage is effected by a screw driven by chain gears and clutches. This motion is entirely automatic, and 12 changes of feed are provided. A handwheel is provided for adjustment, but this is automatically disconnected when the machine is in operation.

The travel of the carriage is controlled by a trip motion which throws out the feed clutch at the end of stroke and starts the quick-return motion. This latter is driven independently of the feed so that the carriage is returned at

the same high speed, whether the cutter is moving fast or slow.

In fact the promptness and accuracy of the automatic return and resetting is the most conspicuous feature of such machines and is a great time-saver. The chips are caught in the base of the machine, the oil strains into the trough around the base and returns to the pump.

Some idea of the capacity of the machine for work may be obtained by studying the speeds provided for. The six changes of speed of cutter range in geometrical progression from 20 to 106 revolutions per minute on this particular machine, and the twelve changes of feed range in a similar way from ·019 to ·263 inch per revolution of cutter. It will readily be understood that all such machines employing the usual circular cutters must waste a considerable amount of time, since during a large fraction of the travel the cutter is either entering or leaving the work and is therefore not cutting to its full capacity. Hence the importance of a careful adjustment of the travel and a prompt indexing mechanism.

A machine similar to the one shown in Fig. 94 and manufactured by the same company is intended for cutting bevel gears up to 18 inches in diameter. This necessitates a tipping table like that shown in Fig. 93 and an arrangement for setting the cutter either side of the centre. It is of course understood that a bevel gear tooth shaped by a milling cutter can be but an approximation to the true shape. By selecting a cutter of the right size, setting it to the proper depth, and milling but one side at a time, the approximation can be made reasonably close in small gears, but large gears should not be cut in this way. Fig. 95 illustrates another machine of the same general type as that shown in the preceding figure but one which differs considerably in detail.

This machine is manufactured in seven sizes, cutting gears up to 103 inches in diameter and 20 inches face. The particular machine shown has a capacity of 64 by 20 inches by

$1\frac{1}{4}$ pitch, and is intended more particularly for work on steel gears.

The headstock in this machine is particularly massive, and is symmetrical with the bed, affording double support to the slide which carries the work spindle. The face plate and

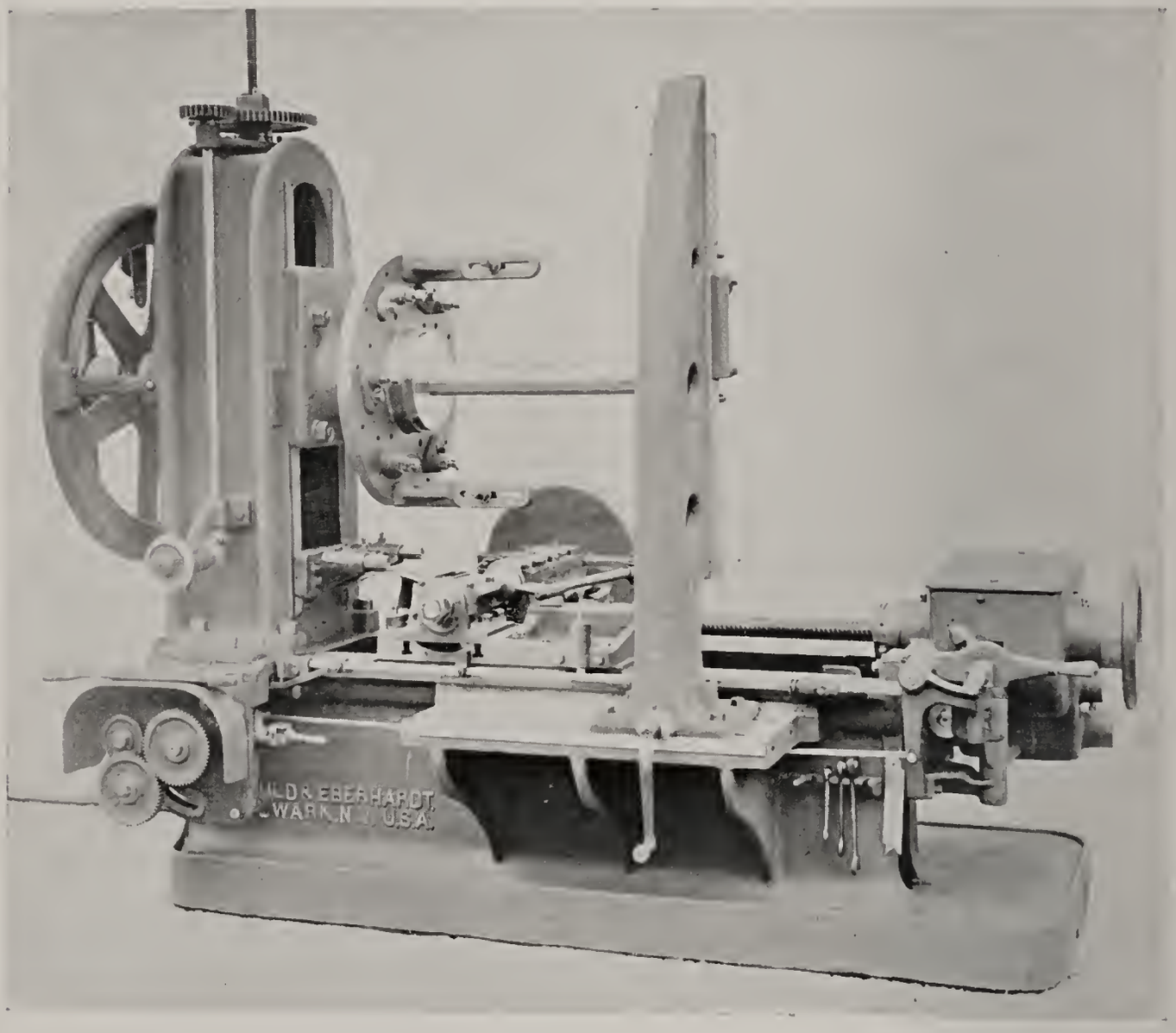

FIG. 95.

AUTOMATIC GEAR CUTTING MACHINE.

Messrs. Gould and Eberhardt, Newark, N.J.

dogs for holding the work will ensure rigidity and greater accuracy in indexing for large gears. On the 103-inch machines an automatic clamp is provided in front of the work, which grips the gear blank firmly while the cutter is engaged, and is released by a trip motion for indexing. The outer support for the spindle is a box-casting of considerable rigidity, and is adjustable by a rack and pinion. Adjustable

stops under the sliding head hold the blank firmly against the pressure of the cut. The cutter arbor has long bearings at each end, and the carriage has long slides gibbed to prevent springing. The action of the machine is automatic, the carriage being fed forward slowly and returned rapidly by means of a screw and a system of clutches operated by a trip motion. The automatic feed can be disconnected at any time, and the carriage fed by the hand-wheel at the extreme right. The indexing is not as rapid as on some smaller machines, but probably as much so as is consistent with good work when such heavy blanks are to be handled.

130. Gear-Shaping Machines.

All the machines so far described have used the milling cutter for a tool, and have depended on the accuracy of the cutter to ensure the correct shape of tooth. If the cutter is properly made and properly ground, the results may be entirely satisfactory, but the burden is thrown entirely upon the manufacturer of the cutter. The problem of shaping, hardening, and grinding such a cutter is a serious one, and will be further discussed under the head of cutter grinders.

Furthermore, any one cutter is correct only for one pitch and one number of teeth. Practically it is necessary to use one cutter for several different numbers on account of the expense, but this is an approximation. For instance, one well-known firm of manufacturers offers eight cutters for cutting all the involute teeth of one pitch, from 12 teeth to a rack. Four additional cutters are special, and can be had by ordering. For epicycloidal teeth, 24 cutters constitute a set. This method is probably accurate enough for ordinary work, but it is an approximation. Several machines have been built and put in operation at different times for overcoming this difficulty, and have been more or less successful. The same idea has been in all—to use some simple and easily duplicated form of cutter which shall cut,

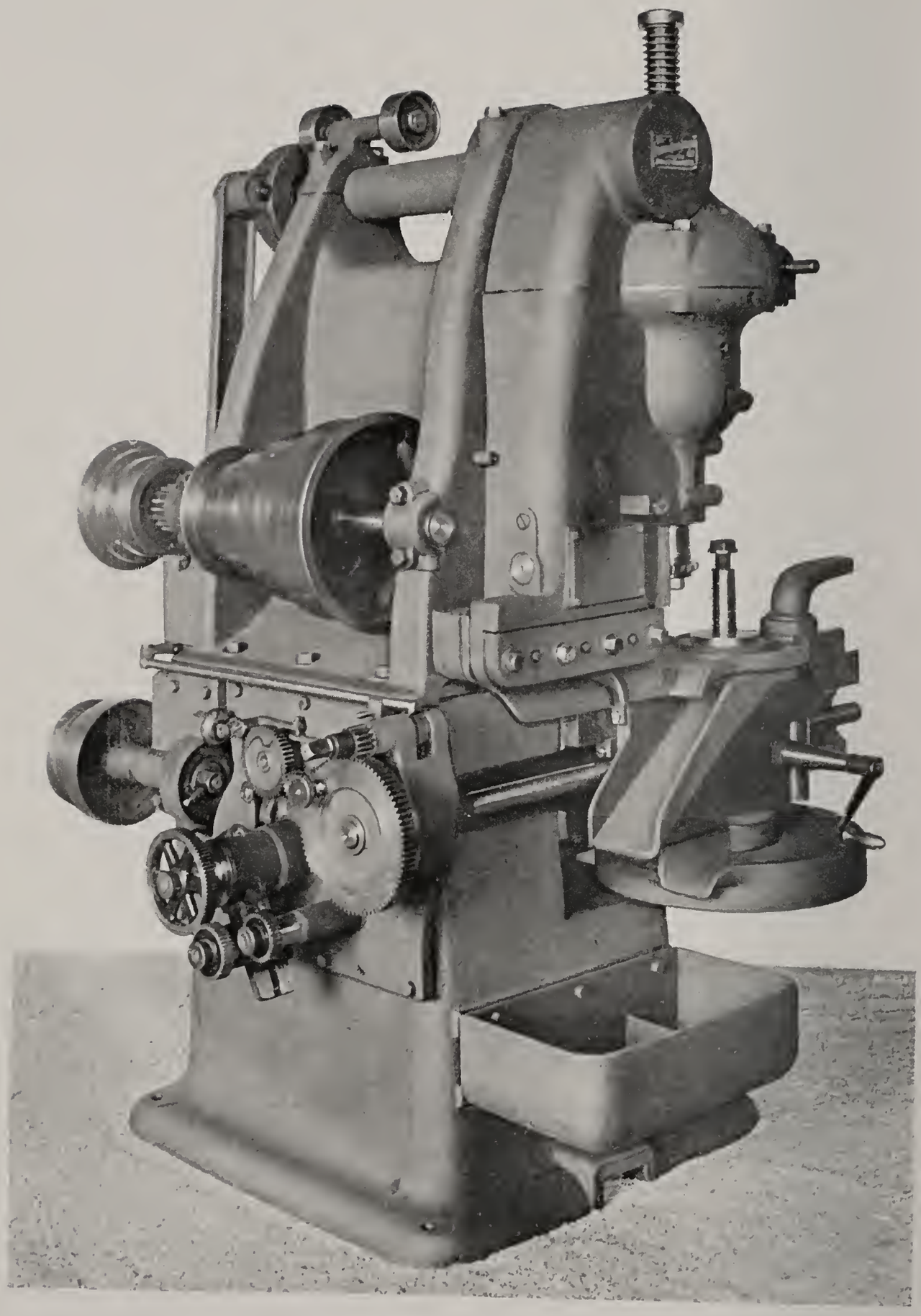

FIG. 96.

24-INCH GEAR SHAPER.

The Fellows Gear Shaper Co., Springfield, Vermont.

or rather generate, automatically all the teeth of a set of wheels of the same pitch.

The straight outlines of an involute rack tooth have naturally suggested the use of this as the base of the system. One inventor has used a cutter similar to the hob of a worm-wheel, but modified to suit the conditions for spur gears. The machine illustrated in Fig. 96 belongs to the class of gear-shaping machines and is in successful use at the present time. In brief, this machine uses a cutter of the shape of an involute pinion which reciprocates on a line parallel to its axis to cut the teeth. At the same time, the cutter and the gear blank are given by suitable gearing a relative rolling motion, the same as if gearing together. The pinion is thus used to shape conjugate teeth for all wheels of the set, and one cutter suffices for all teeth of the same pitch.

The cutter itself consists of a thin steel disk with involute teeth of the desired pitch backed off so as to form cutting edges. The teeth can be sharpened by grinding the front face without changing the shape.

The involute curves of the teeth are generated by rolling the cutter past a flat emery wheel with the motion that a pinion has relative to a rack. The flat surface of the wheel set at the proper angle represents the rack tooth and generates automatically the corresponding involute of the cutter tooth. In duplicating cutters by this method, it is only necessary to preserve a truly plane surface on the grinding wheel, and the machine takes care of the rest. The cutter, when properly hardened and ground, is placed in the machine and given a reciprocating motion along its axis. It is then fed against the work until the proper depth is obtained, when gear blank and cutter begin to revolve together just as if in mesh, the correct relative motion being produced by a train of gears. Fig. 97 shows the nature of the motion and the successive cuts made by one tooth of the cutter.

An examination of this figure shows that the shavings

removed would all have a thin edge next to the tooth being cut, which should produce a nicely finished surface. The stroke of the cutter can be adjusted so as to just clear the blank and thus eliminate the lost motion inherent with rotary cutters. It will be seen that this is not a milling machine, but a shaper using a cutter of peculiar form and path. As may be seen by reference to Fig. 96, the machine is of the vertical type, having a cabinet base. This base supports the headstock

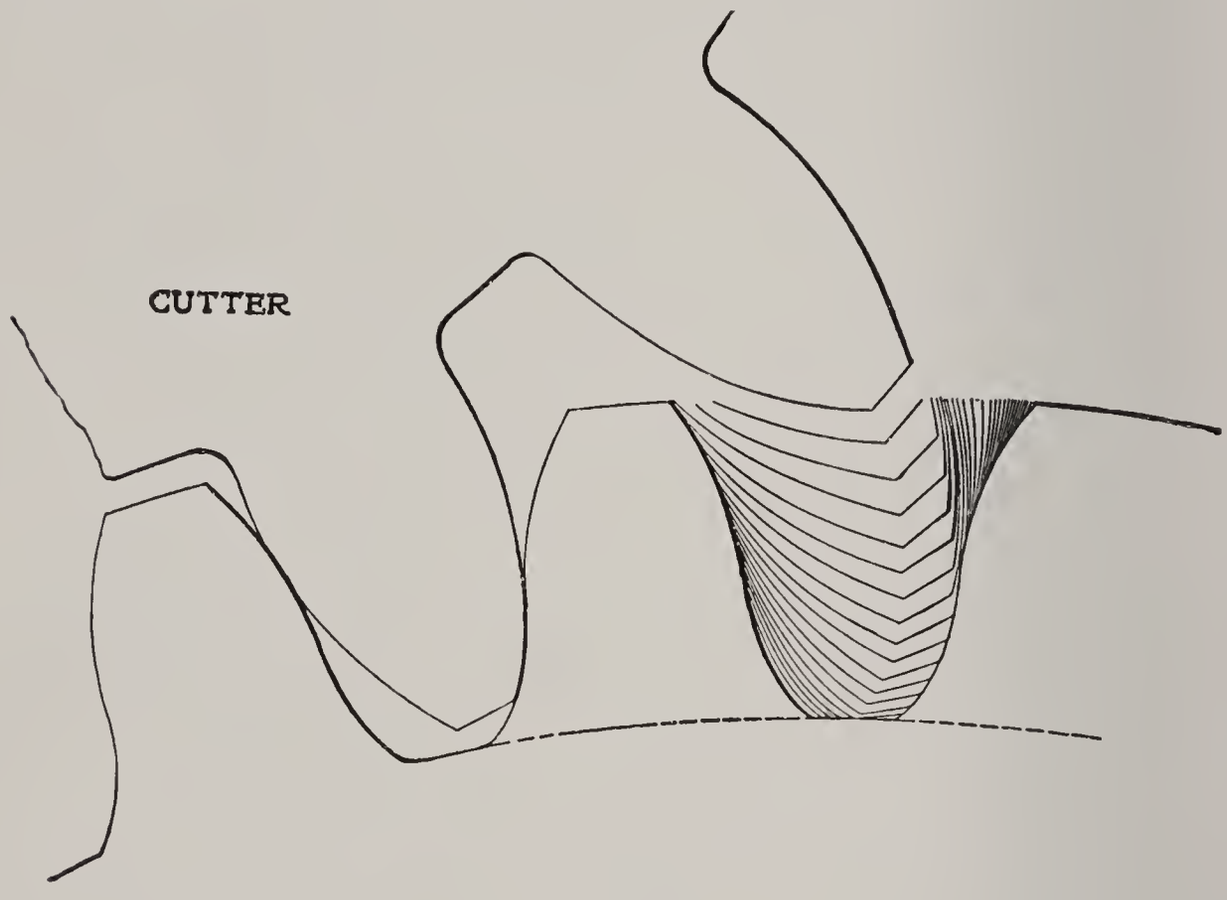

Fig. 97.

ACTION OF CUTTER OF GEAR SHAPER.

for the cutter spindle and the carriage for the work. The cutter spindle has two motions, one vertical produced by a crank and pitman, the other a rotation due to a train of gears connecting it with the work spindle. The downward stroke of the spindle is counterbalanced by the spring shown at the top. It is intended that the machine shall cut on the up or draw stroke, but by reversing the position of the crank pin a downward cut can be obtained.

The work spindle carries an arbor, upon which several gear blanks may be clamped at once. The carriage can then

be traversed on the horizontal ways to bring the blanks the right distance from the cutter, a gauge being furnished for setting them. There is a separate adjustment for depth of cut controlled by a graduated wheel. This wheel shows on its rim the settings for any desired pitch, and can be used when cutting a number of wheels of the same size, without disturbing the position of the carriage on the ways. The stroke of the cutter is adjusted by means of a slotted crank which drives the pitman. During the cut the work is supported by a stop or abutment near the cutter. A support is also supplied for the top end of the work arbor.

In starting the machine, both the depth and the rotary feeds are put in operation. The cutter then feeds automatically towards the work, until a proper depth has been reached, when the depth feed is automatically thrown out and both cutter and wheel begin to rotate slowly at the correct relative speed. This action continues until the blank has made one rotation, when action ceases automatically. The advantages claimed by the makers of this type of gear cutter are in brief: 1. That one cutter will generate all the teeth of one pitch. 2. That the cutter can be duplicated accurately by grinding on a plane surface. 3. That there is no waste motion in the stroke. 4. That the cutter will work on internal gears and in narrow recesses, where it would be difficult to operate the ordinary cutter. It is also claimed that more gears can be cut in the same time than by the usual method. The writer knows of no published data on this point. There is, however, no doubt as to the correctness of the process, and it may be regarded as a very ingenious solution of the problem. Internal gears may be cut after a fashion on the ordinary type of gear machine, by hanging the rotating cutter on a projecting arm containing a train of gears, but the device is rather awkward and unsteady in appearance. If a machine, like the one just described, should bring about a more general use of annular gears, it would make a valuable improvement in machine design.

131. Gear-Planing Machines.

The tooth of a spur gear is cylindrical, and the profile is the same from end to end, while the tooth of a bevel gear is conical, and the profile continually changes. Any process

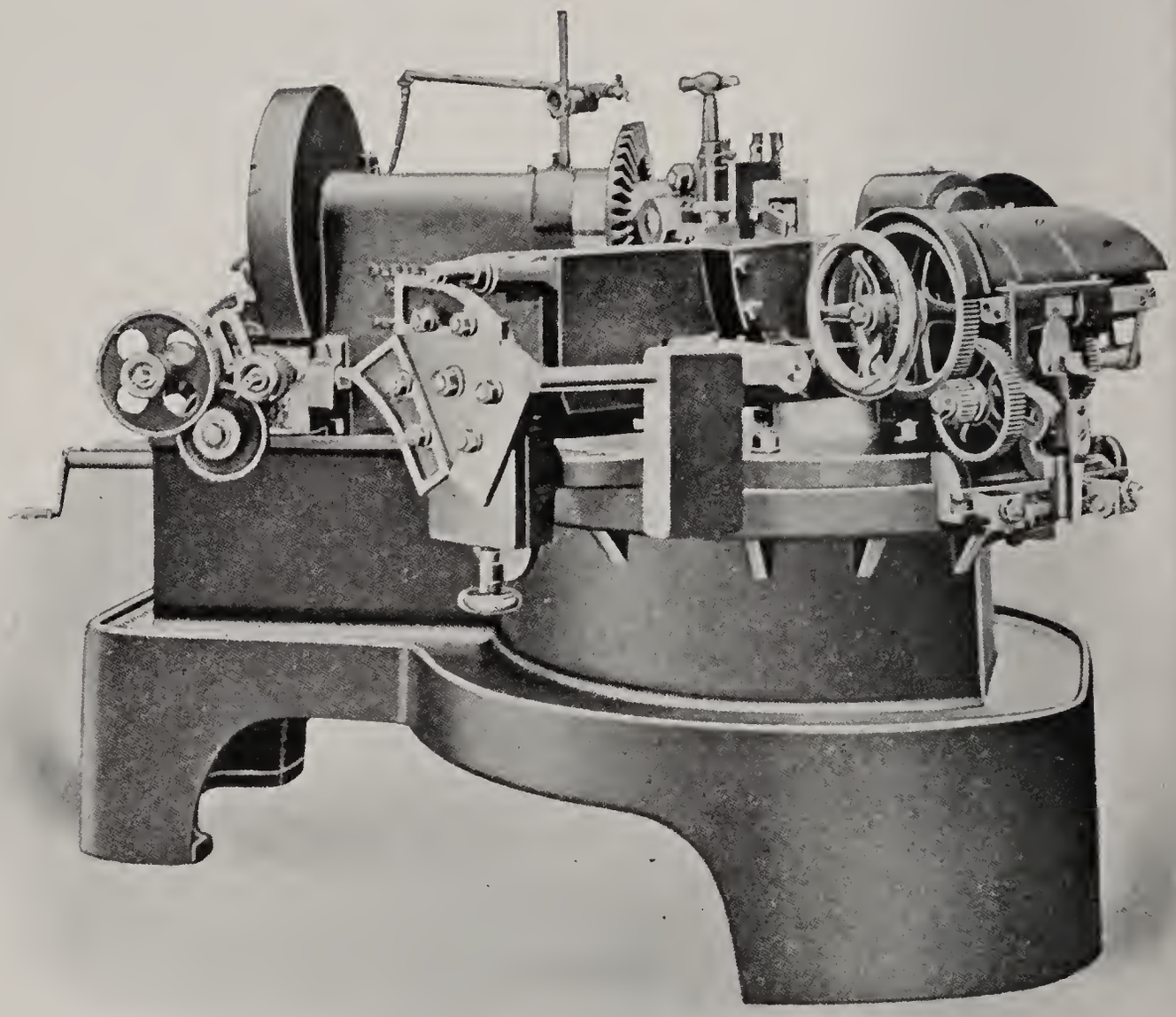

FIG. 98.

24-INCH BEVEL GEAR PLANER.

Gleason Works, Rochester, N.Y.

of cutting, therefore, which involves a parallel cut of sensible breadth, either by milling or shaping, is incorrect for bevel gears. As has already been noticed, it is practicable to cut small gears with narrow faces on the ordinary machine without serious error. Any attempt to use this method on

large gears, or those having faces of considerable width, results in gearing so imperfect as to cause trouble in running.

The elements of bevel gear teeth are straight lines converging to the point where the gear shafts intersect. The most correct approximation to their shape is therefore obtained by using narrow cuts of a planing tool converging to the same point. The tool is to be guided by a template or other device, and the accuracy of the work will depend on the accuracy of this template and the fineness of the feed.

This principle is old, and has often been employed in such machines in one form or another.

Fig. 98 represents a gear-planing machine constructed on this principle, and adapted for gears up to 24 inches in diameter, and any bevel. The gear blank is mounted on a horizontal spindle as may be seen in the figure, and the tool travels approximately in a horizontal line along a radial arm. This arm can be swung to any angle in the horizontal plane to accommodate different bevels, and being hinged at the centre, it has also a limited vertical movement. At the outer end of the arm is a roll bearing on a steel former, having an outline similar to that of the tooth in a magnified degree. As the arm swings horizontally to feed the tool into the work, the roll travels on the former, ensuring the correct outline for the tooth. Three formers are shown attached to a revolving plate so that any one may be brought into position. There is a former for each side of tooth, and a straight one for the roughing or gashing cut. The formers are produced by a machine which generates the correct curve, so that they may be relied upon to give exact results. Involute formers are furnished with the machine, but epicycloidal ones can be made to order. The tool slide is driven positively by gears, and has the Whitworth quick return. The machine is automatic as to return of tool and indexing, the same as a spur-gear machine.

Similar machines are made for planing spur gears of a pitch too coarse to be economically milled. These machines

are especially adapted for planing teeth which have been roughly cast to shape, a method which is sometimes more economical than cutting from the solid. Internal spur gears can be cut in the same way by employing a special tool-holder. Machines are built for planing spur gears up to 20 feet in diameter, and for bevel gears up to 8 feet in diameter.

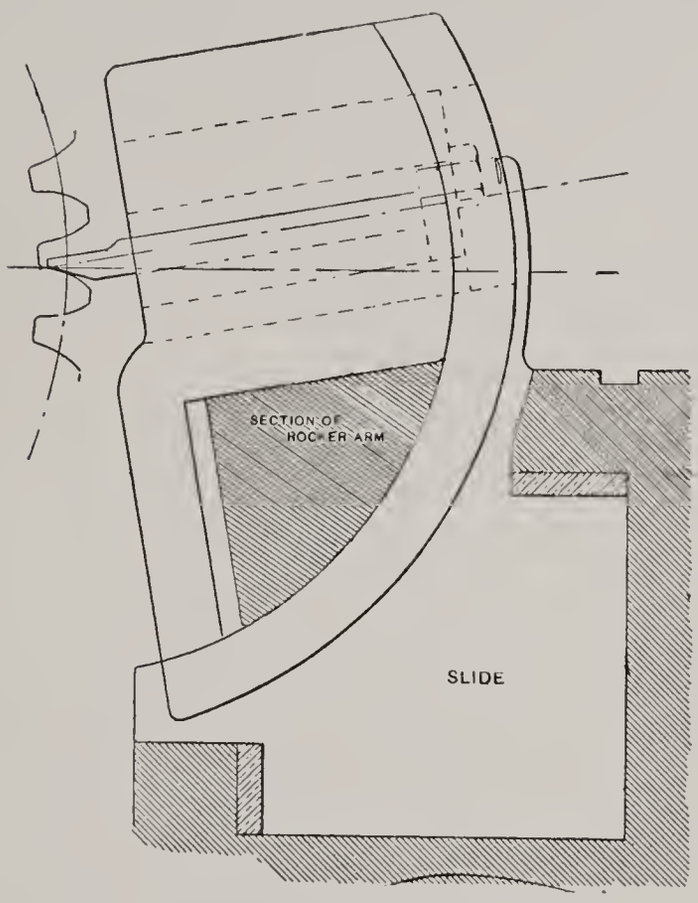

FIG. 99.

DETAIL OF CUTTER ARM, GLEASON PLANER.

A smaller machine, intended for cutting gears up to 15 inches in diameter, works on a different principle. The tool cuts with the side instead of the point, thus producing a smoother surface. A peculiar rolling motion is given to the tool, which may be understood by reference to Fig. 99.

The slide which carries the tool has a reciprocating motion in a line through the apex of the gear cone, as in the machines just described, and the arm is advanced to feed the tool into the work. Instead, however, of being guided by a former, as in Fig. 98, the tool-holder is turned through a certain angle, so that the tool, as it advances into the work, rolls on the tooth, and is always tangent to the true curve. The motion is controlled by a cam at the outer end of arm, this cam being actuated by the advancing motion of the arm. By an ingenious reversing device, the same cam is made to serve for either side of tooth. Three tools are used, one for gashing the blank, and one for each side of tooth. Box tools are used on all these machines, and after having been once adjusted, can be removed for grinding without readjustment.

132. Thread-Milling Machines.

Formerly, all screw threads were cut by dies, or on the engine lathe. For ordinary bolt and screw work, the die machine still holds its own, but it is manifestly not suitable for lead and feed screws, where great accuracy is desired. The engine lathe does this latter class of work well, but at a great sacrifice of time and patience. The thread milling machine, although comparatively a new tool, has already demonstrated its right to be considered the most economical machine for the production of accurate screw threads of all descriptions, including those on spiral gearing. Fig. 100 gives a rear view of one such machine adapted for milling work up to 6 inches in diameter and 14 inches long. A similar machine is built with a longer bed for screws up to 80 inches in length.

The cabinet base, the pan, and the bed for the support of the working parts are about the same as for the ordinary turret lathe or screw machine.

The headstock carries a compound or double spindle consisting of an outer sleeve running in bearings, and driven by gearing and an inner spindle carrying the collet for holding the work.

There is a ratchet and pawl connection between the two which can be so set as to automatically turn the blank into the right position when multiple threads or spiral teeth are to be cut.

During the return the machine is driven directly at quick speed by the grooved pulley on the spindle. When cutting, the machine is driven by gearing from the grooved cone pulley on the rear of the headstock, and the spindle pulley runs loose. The lead screw which moves the carriage may be seen just above the ways, and is geared to the spindle at the right end. In cutting fine threads the spindle is driven by the cone pulley, and in turn drives the lead screw. When

screws of steep pitch or spiral gears are to be cut, the gearing is changed so that the lead screw is driven directly by the cone pulley, since the greater power is needed on the traverse motion.

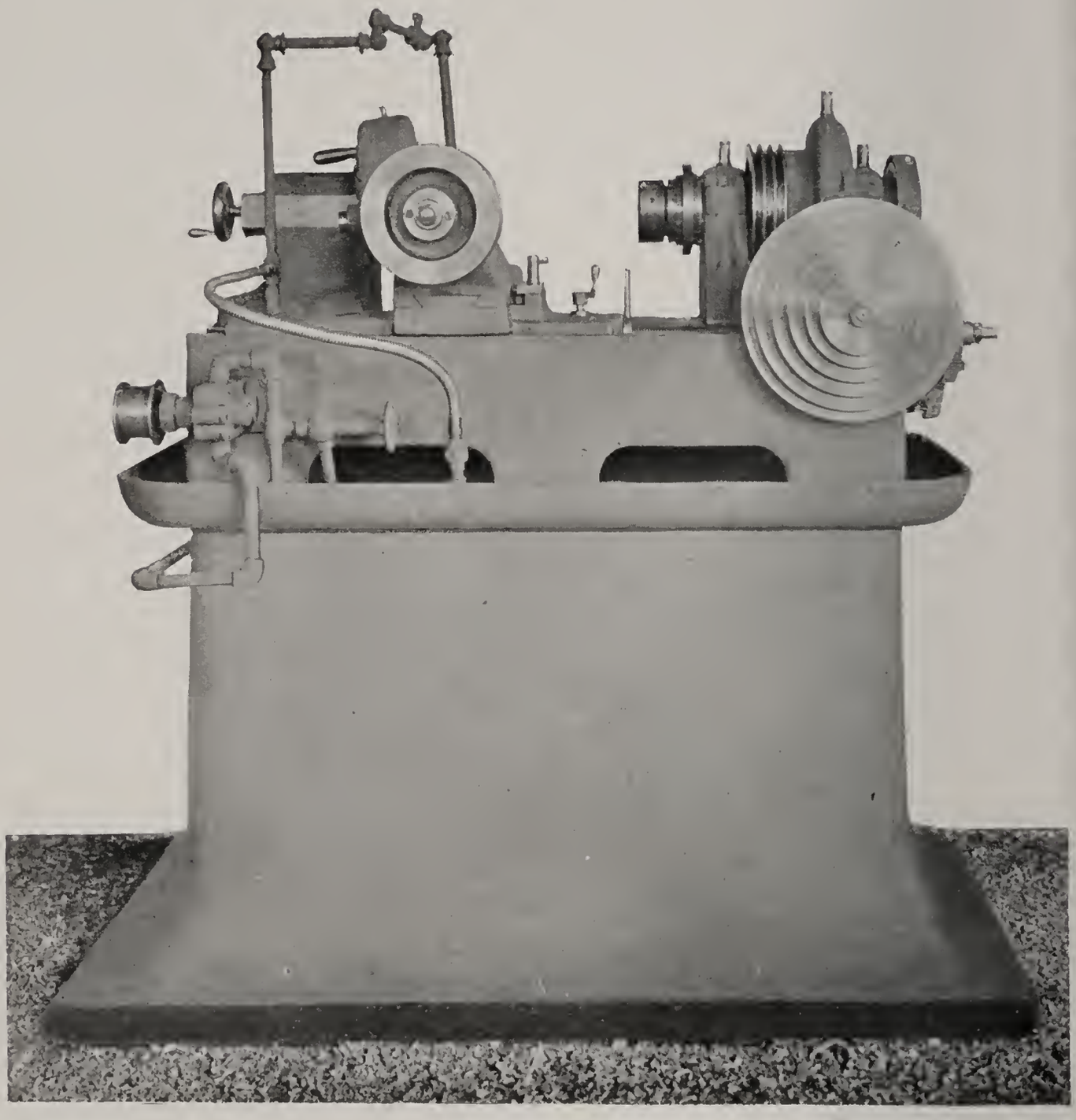

FIG. 100.

6-INCH × 14-INCH THREAD MILLER—REAR VIEW.

The Pratt and Whitney Co., Hartford, Conn.

By using grooved cone pulleys and a round belt it is possible to belt from one step on the upper pulley to either of two steps below, and *vice versa*. Thus there are sixteen changes of speed on the cones, and this is multiplied to sixty-

four by the arrangement of countershafting. It will be noticed that the cutter is driven by independent belting, which makes it possible to use very light belting on the spindle drive. The tailstock needs no special description. The carriage is moved on flat ways and is so gibbed underneath as to prevent any tipping or lifting action. The carriage is driven by the lead screw, and the feed is controlled by a lever in front of the headstock and not shown in the figure. When this lever is moved in one direction the cutting feed is started. When the lever is reversed the carriage returns rapidly to beginning of cut. A trip motion at the front of the machine operated by a dog on the carriage automatically reverses the machine at the end of cut. The feed and trip motions can be adjusted for either right or left hand threads.

The milling cutter is mounted on the carriage in such a way that it may be tipped to right or left to correspond to the obliquity of the thread. This tipping is about a horizontal axis through the cutting point of the tool, so that the point remains always on a level with the axis of the work.

The cutter is driven independently of the rest of the machine through gears on the same axis with the trunnions to allow for the tipping.

The driving pulley is turned by six round belts running in six grooves and coming from a drum above. This arrangement gives the necessary flexibility, and at the same time does away with the danger to cutter and to work which would result from the breaking of a single flat belt.

An adjustment of the carriage on the lead screw is effected by turning the lead-screw nut. When this latter is locked by turning a lever the carriage can be moved by the lead screw alone.

This size of machine is equipped for cutting fine threads on screws $\frac{3}{8}$ inch in diameter, and from that up to the teeth of 6-inch spiral gears. Cutters are provided with staggered teeth cutting alternately on either side, and a

special automatic grinding machine makes it possible to duplicate these with precision. Perhaps no one class of machine tools has done more to advance the cause of precision in iron and steel cutting than the gear and thread cutters. Gears and screws are used on nearly all machine tools, and if inaccurate will perpetuate their failings according to an unalterable law of heredity. The lathe with a poor lead screw will always make poor screws. The milling machine with inaccurate gearing will always make inaccurate gears.

So, whether the manufacturer buys his gears and lead screws of the specialist, or whether he makes them in his own shop, the product of the modern gear cutter and thread cutter is bound to make itself felt as a promoter of accuracy in manufacture.

CHAPTER IX

GRINDING MACHINERY

133. Grinding in General.

One of the marked improvements in machine manufacture during the past ten or fifteen years has been the increase of grinding processes as a means of finishing metal parts. Formerly the grinding wheel was regarded as an agent for coarse rough work, and as an ally rather of the foundry and the forge shop than of the machine shop.

Improvements in the material and make-up of grinding wheels and corresponding improvements in the machines for operating them have made it possible to use them for the most accurate and exacting work. Add to this fact the possibility of finishing chilled and hardened surfaces which could not be cut by steel tools, and you have sufficient reason for the change.

The fact that a piece is finished by grinding does not necessarily prove that it is more nearly correct than a similar piece finished in the ordinary way. At the same time it is practicable to finish with the wheel, if properly used, in such a manner as to equal, if not surpass, any other treatment, and at a less cost.

134. Classification.

The ordinary emery or corundum wheel mounted on a plain stand, and used for the rough work of the shop, need

not be specially considered, as it is hardly a machine. Finishing and special grinders may be classified as follows :—

(1) Surface-grinding machines.
(2) Cylindrical grinding machines.
(3) Universal grinding machines.
(4) Tool grinders.
(5) Twist-drill grinders.
(6) Cutter and reamer grinders.

135. Surface Grinding.

By surface grinding is here meant the production of plane surfaces only. This may be accomplished in several different ways, by the use of cylindrical wheels cutting on the periphery, by ring wheels cutting on the annular face, or by flat discs covered with abrasive material. When the cylindrical wheel is used, the plane surface must be obtained by the traverse of the wheel or of the work, in two directions, as in Fig. 103. With the ring wheel, such as shown in Fig. 102, dependence can be placed on the face of the wheel for securing a plane surface just as in the rotary planer, and the table is fed longitudinally. When the flat disc made of steel is employed as in Fig. 101, the disc itself is supposed to give the necessary plane surface, and the table is merely used to guide the work.

Surface grinders are not generally used to remove large quantities of metal from castings or forgings, since this can be more economically done by the planer or the milling machine. When, however, it is possible to cast or forge quite near to the finished size, as in small machine parts, the grinding machine can be profitably used for removing a thin layer of metal. Unlike planing or milling machines, the grinding machine does not need to get below the scale in order to work satisfactorily, and can finish by removing $\frac{1}{64}$ as well as by removing $\frac{1}{8}$ of an inch of metal.

Grinding machines which have automatic tables as in

Figs. 102 and 103 are profitably used for finishing to size pieces which have already been roughed out on the planer. Any degree of smoothness or polish can be given in this way by using the proper grade of wheel and the tool marks com-

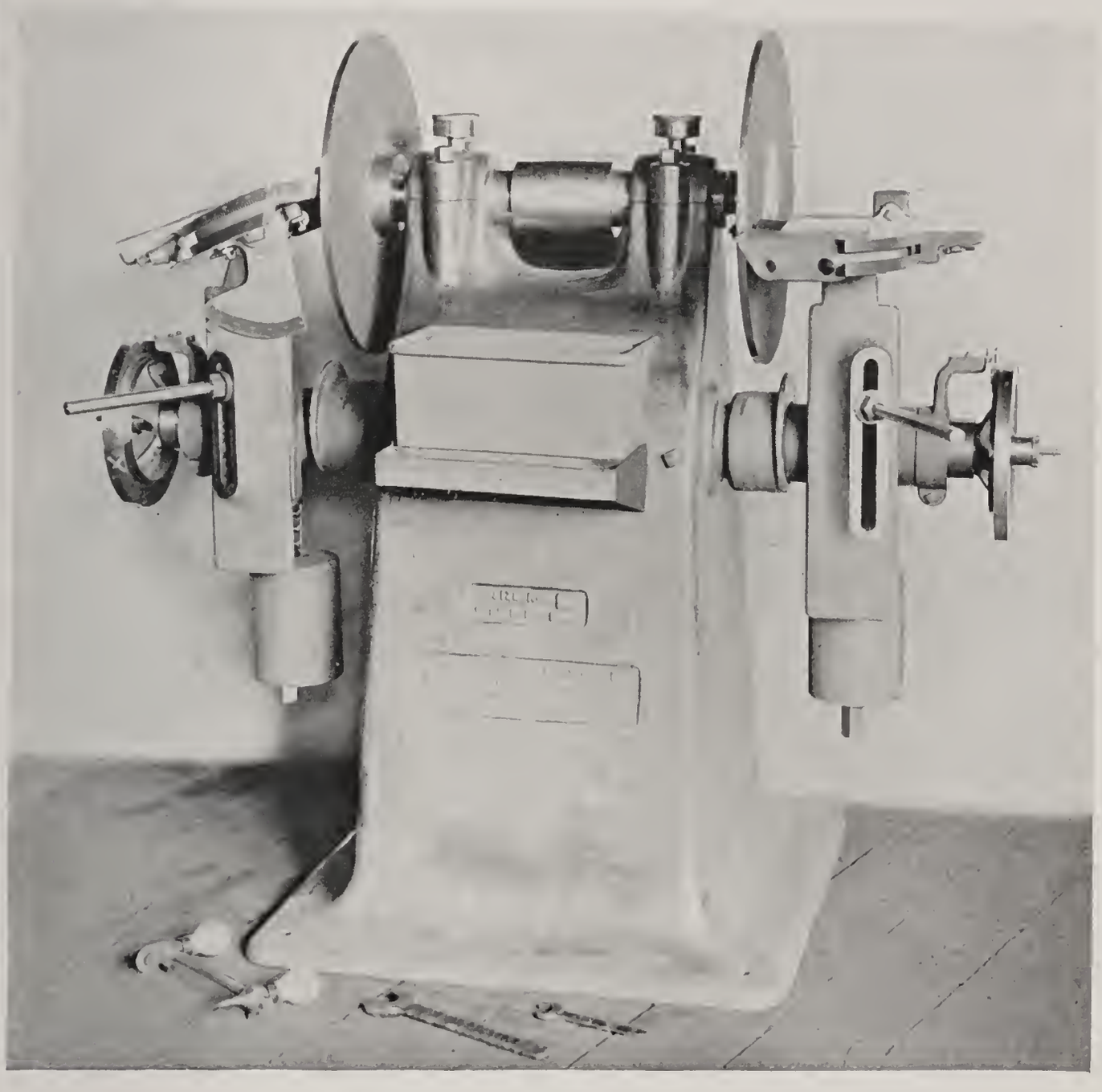

FIG. 101.

UNIVERSAL DISC GRINDER.

Diamond Machine Co., Providence, R.I.

pletely effaced. Perhaps the most important field of the grinding machine, and one which is peculiarly its own, is the surfacing of machine parts made of chilled iron, of hardened steel, or of any alloy which is too hard to be cut in the ordinary way.

136. Disc Machines.

Disc machines, such as the one shown in Fig. 101, are intended more for use in finishing small pieces which can be held by hand or at least adjusted by a hand feed.

The Gardner disc grinder differs from others in its class in having a spiral groove on the face of the steel disc. This groove assists in the holding of the glue by which the emery cloth or paper is secured to the disc, and also gives the emery a corrugated surface, which ensures more rapid cutting. The discs on this machine are of open-hearth steel, about 18 inches in diameter and $\frac{7}{16}$ inch thick. The spiral groove is $\frac{3}{64}$ inch wide and $\frac{1}{32}$ inch deep, 5 grooves per inch of radius. A wheel of this size can be safely run at 1800 revolutions per minute, or over 50 per cent. faster than the safe speed of a solid emery wheel of the same diameter.

The table is a swinging one, counterweighted and adjustable at different angles with the face of the disc.

The machine is sometimes driven directly by an electric motor, the starting box being in the base or cabinet. The high speeds at which grinding machines are run makes the use of electric driving much more simple than for ordinary machine tools.

In Fig. 101 may be seen a disc machine of a different type. The discs are of steel, but are plane, and a special cement is used in securing the cloth or paper. This machine differs from the machine just described in the construction and operation of the tables. The upright carrying the table has a swinging motion on a stud or shaft projecting from the base of the machine, but may be clamped in any desired position. The upright has a vertical adjustment, and as it is raised or lowered it automatically adjusts the counterweight by means of a chain and pulley, so as to keep the table in equilibrium. The table may be moved to and from the disc by the micrometer wheel shown, and an adjustable stop is provided to regulate the depth of cut.

The quadrant for tipping the table is shown at the left of the machine. This is graduated to show the exact angle of inclination. On the top of each table is a protractor swinging in the plane of the table about the centre of the disc and read by graduations on the rim of the table. It is possible with this table to set the work at any desired angle in the vertical or the horizontal plane, and by the use of the feed screw and micrometer to cut to any desired size or depth.

The machine runs at 1800 revolutions per minute, and according to the statement of the makers is capable under favourable conditions of removing from 4 to 6 cubic inches of tool steel in an hour from the end of a bar one inch square without renewing emery paper.

137. Ring Wheels.

When wheels of emery or other powder bonded together with adhesive material are to be employed, the flat disc becomes impracticable, and a cup wheel or ring wheel is used. Such a wheel cuts with the comparatively narrow face of the ring and gives a true surface. Even if this face becomes worn a traverse motion of the work in the plane of rotation will develop a plane surface just as in rotary planing or end milling. Fig. 102 shows a ring-wheel grinding machine with automatic table and adjustable head. The wheel itself is in the shape of a hollow cylinder and is held in a concentric chuck of cast iron. The wheel is backed up by a circular flange nut which can be adjusted as the face of the wheel wears off. The clamping is effected by a taper ring outside the wheel held by a series of bolts. The wheel is thus guarded against bursting, a danger to which ring wheels are peculiarly liable, and at the same time can be adjusted for wear until completely worn out.

The wheel spindle is carried in a sliding head which can be raised or lowered on the upright to accommodate different sizes of work. The head and upright are moved to and from

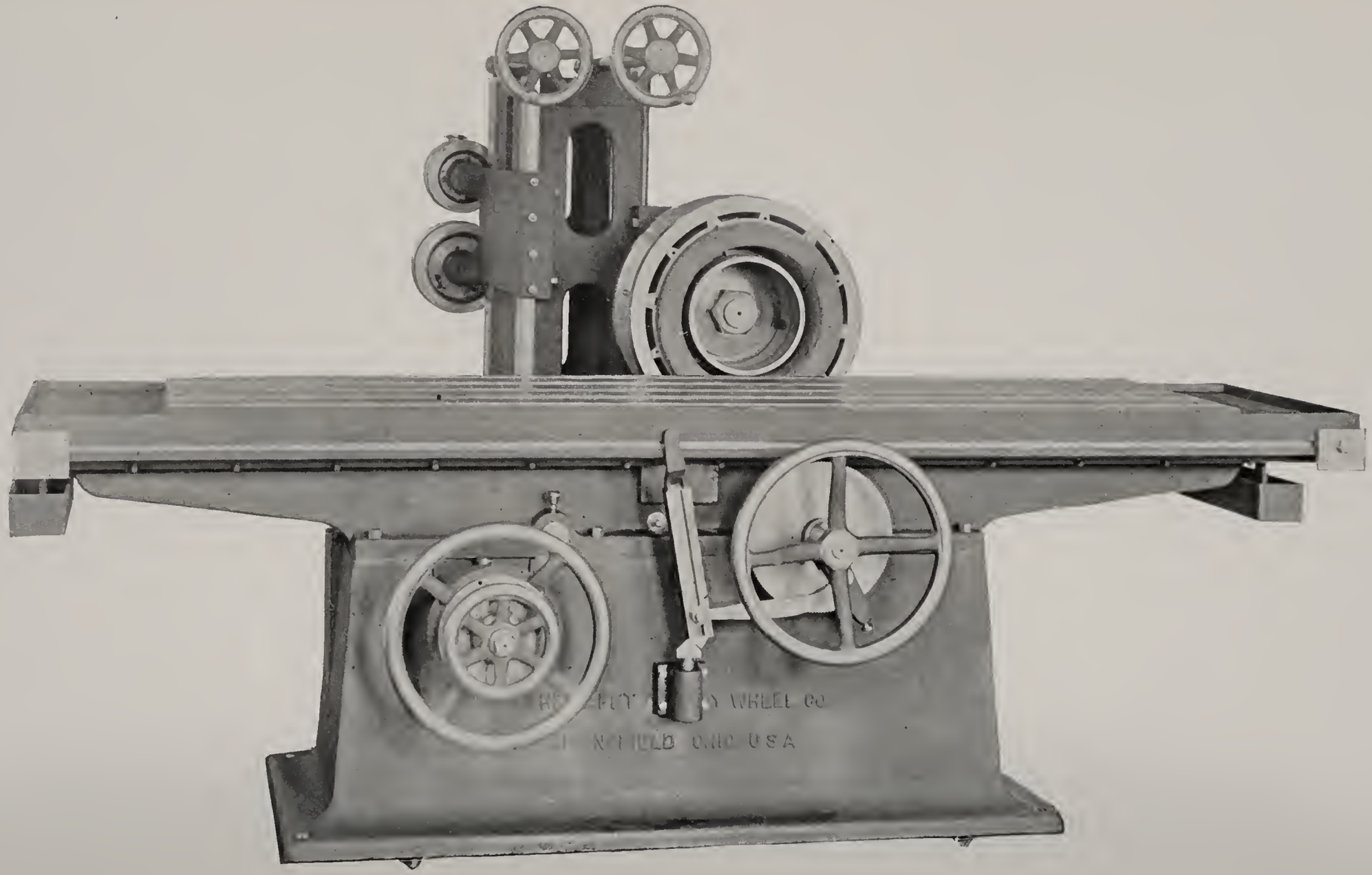

Fig. 102.

RING WHEEL GRINDER.

The Safety Emery Wheel Co., Springfield, Ohio.

the table by a feed mechanism operating automatically at each traverse of the work. The feed can be regulated from 0 to $\frac{1}{8}$ inch per stroke. The table or platen is similar to that of a planer and reciprocates on ways cast to the bed. Dogs on the table regulate the stroke and reverse it automatically. The control of both table traverse and wheel feed is secured by hand-wheels at the front of the machine conveniently located for the operator. Such machines are built in lengths ranging from 50 to 180 inches. The machine shown in Fig. 102 will take work 80 inches long, 22 inches wide, and 12 inches high.

138. Machines with Cylindrical Wheels.

The grinding machine which is most universal in its application is probably the one employing a cylindrical wheel cutting either on the rim or on the face. Fig. 103 illustrates such a machine built in a form similar to that of the open-side planer.

The grinding wheel is carried on a spindle having an outer support, carried by an overhanging arm as in the milling machine. An especially long box also affords support to the spindle. The spindle or arbor is mounted on a sliding head, which in turn is clamped to the housing or upright of the machine and can be raised or lowered by means of elevating screws. The sliding head can also be swivelled by loosening the nuts in the centre, so as to tip the wheel slightly in facing down vertical surfaces. To accommodate the various adjustments of the head, the belt from the countershaft is led over idle pulleys which can be shifted to keep the proper tension. The upright is broad and has large bearing surfaces, both for the sliding head and for its own contact with the bed. It is gibbed to the ways on the bed to ensure rigidity, and is fed by a screw to or from the table at each traverse of the latter, thus making it possible to cover the entire surface automatically. This feed motion

can be varied from 0 to $\frac{1}{8}$ inch for each traverse. As is shown in the cut, the table travels on flat ways to which it is gibbed, and is driven by rack and gears. If it is desired to do wet grinding, the water is drained from the table and

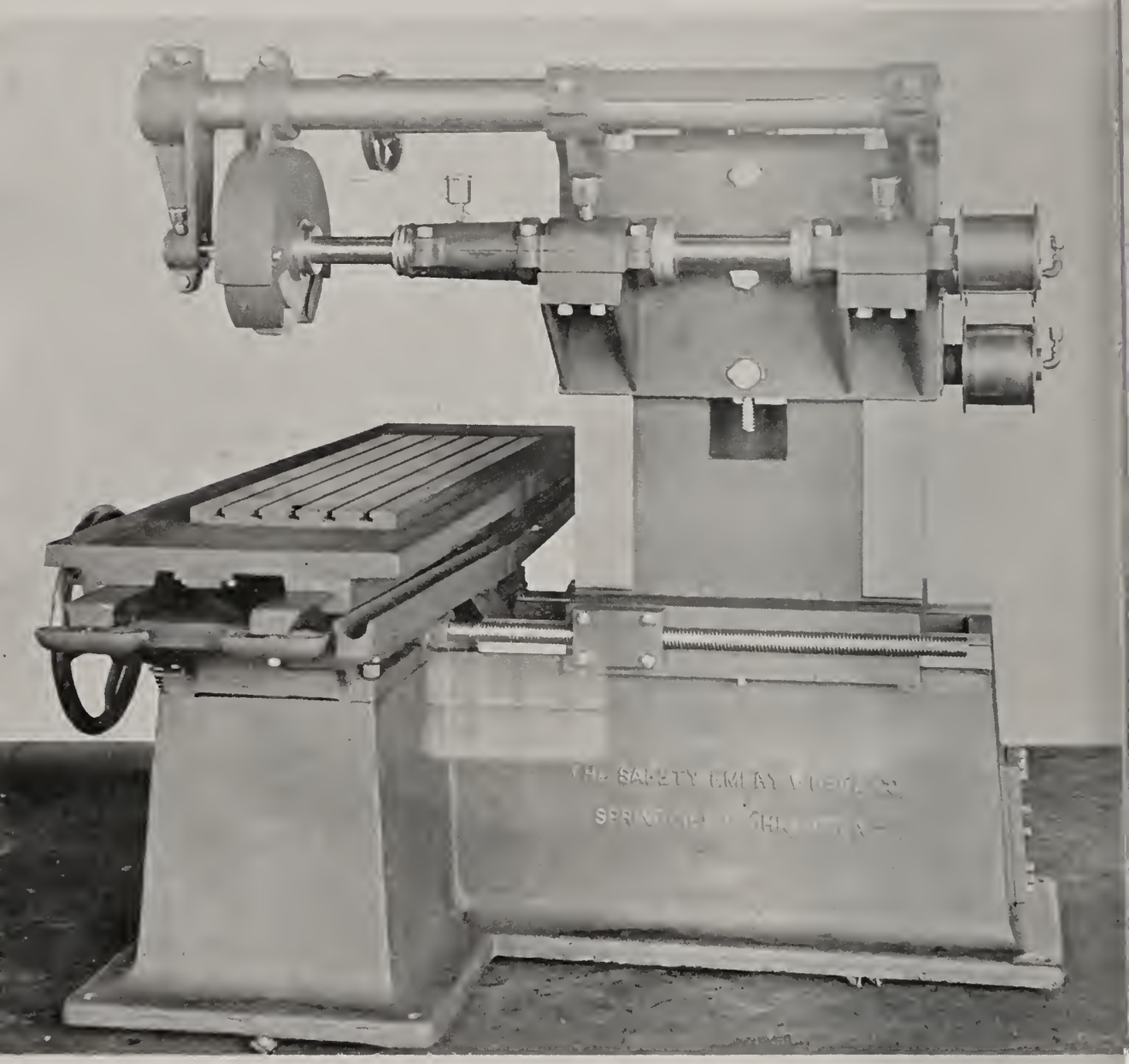

FIG. 103.

OPEN SIDE SURFACE GRINDER.

The Safety Emery Wheel Co., Springfield, Ohio.

carried to a tank in the base of the machine. The table is controlled by a friction clutch so that it may be stopped at any time and operated by hand.

The wheels used on these machines are provided with

safety collars, which grip shallow hubs on the faces of the wheels and safeguard them against rupture. With these collars it is deemed safe to run the wheel at surface speeds of 6000 to 6500 feet per minute.

The various hand-wheels for adjusting and controlling the machine are located within reach of the operator at the front. A small surface grinder (made by the Walker Company of Worcester, Mass.) is directly driven by an electric motor on the spindle. The machine is also furnished with a magnetic clutch built into the platen for holding small pieces of work. The chuck is magnetised or demagnetised by the starting and stopping of the machine and requires no special attention.

The necessary vertical adjustment is in the head carrying the wheel and is fitted with a micrometer. The platen reciprocates on a carriage or saddle which moves transversely for the cross feed. Both of these motions are controlled by a motor in the base of the machine. The platen can be operated automatically without the cross feed, or both can be run at once. Variable speed for the platen is secured by the electric drive, and electric lamp and alarm bells complete the outfit. This machine is interesting as an example of what may be done in the way of electric driving and control.

The fact that the entire machine is driven by one electric wire makes it possible to move the machine from place to place. It is accordingly fitted with wheels to facilitate its being transported.

139. Cylindrical Grinding Machines.

Grinders which are used for producing cylindrical and conical surfaces are classified as plain and universal, much the same as are milling machines.

The plain machine is capable of grinding straight or taper shafts up to a certain limit, but cannot be used for the variety of work done on the universal machine. Like its cousin, the plain milling machine, the plain grinder is simpler, has less

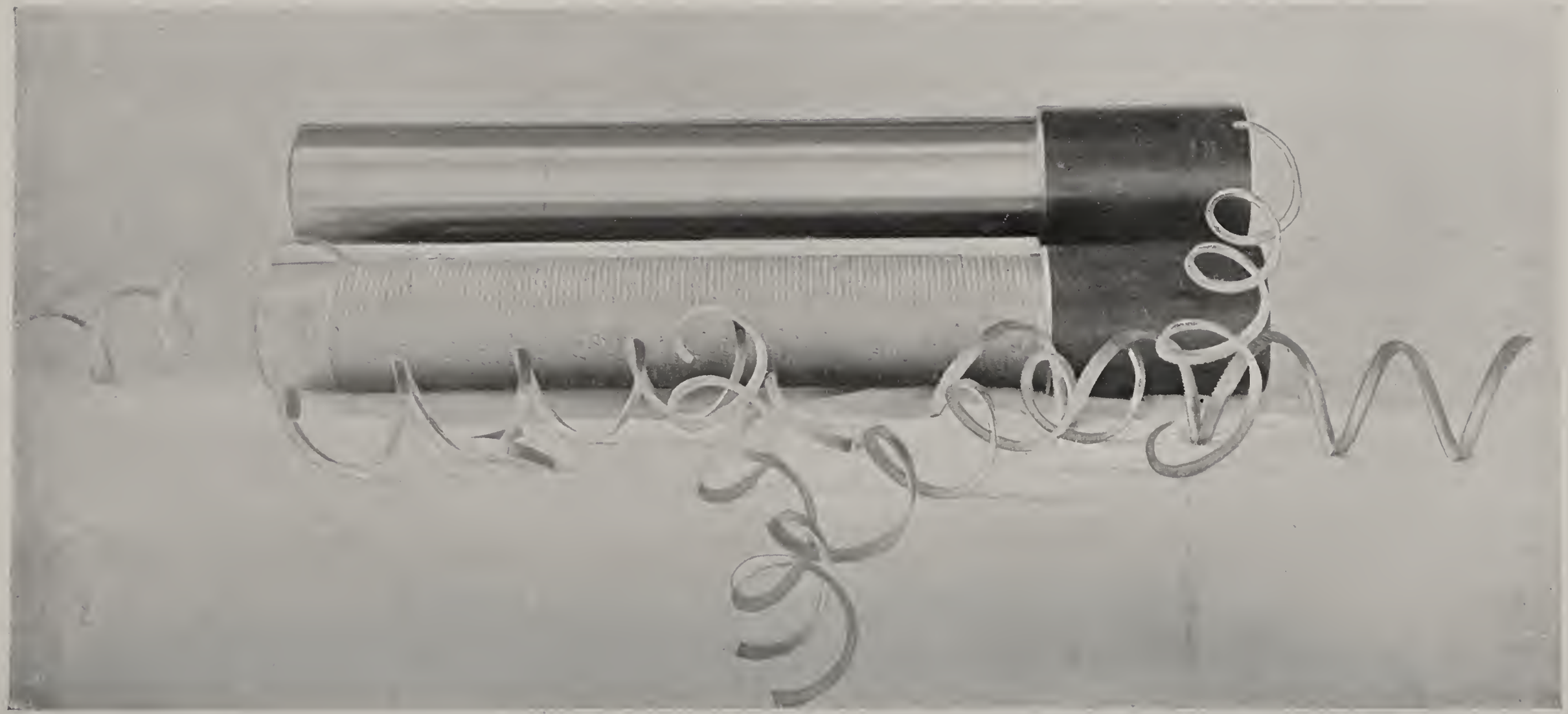

FIG. 104.

MODEL SHOWING METHOD OF TURNING FOR GRINDING.

joints and adjustments, and is the better machine for plain work.

As has been already said in discussing surface grinders, it does not usually pay to remove large quantities of soft metal by grinding. The part to be finished had better be roughed off in the lathe, as illustrated in Fig. 104, to within $\frac{1}{64}$ or $\frac{1}{32}$ inch of size, and then finished by grinding. As shown in the figure, it is not necessary to take a finishing cut in the lathe, but merely to reduce the piece to somewhere near the desired size in as rapid a manner as possible. Where machine parts are to be hardened and then ground, a closer finish in the lathe is necessary, leaving only a few thousandths to be removed by grinding. A plain grinding machine must have the following motions or adjustments in order to do the work :—(1) A rapid rotation of the wheel usually at a surface speed of from 5000 to 6000 feet per minute; (2) a slow rotation of the work, about the same as in a lathe, from 25 to 75 feet per minute; (3) a traverse of either wheel or work longitudinally at the rate of from one-quarter to three-quarters the width of emery-wheel face for each revolution of the work; (4) a cross feed or adjustment for setting the wheel to give the proper diameter of work; (5) a swivelling of the table carrying the work to produce taper cuts. Some manufacturers prefer to move the wheel and some to move the work in getting the necessary traverse.

Fig. 105 shows a rear view of a machine where the work-table moves longitudinally and the wheel head remains stationary. The rear view was chosen to show more clearly the driving mechanism.

The head carrying the wheel arbor is massive in construction, so that its own weight keeps it down on the ways. The head slides to and from the work to regulate the depth of cut, having one flat and one large V-shaped way. This motion is, of course, regulated from the front of the machine with a micrometer. The machine shown in Fig. 105 may be driven by a constant-speed motor. The countershaft which

drives the wheel is hung in a hinged frame, and this can be adjusted to tighten the belt running to the wheel arbor. The motor drives the countershaft through a belt which is tightened by an idle pulley and weight, thus maintaining a constant belt tension as the head is moved in or out. The overhead countershaft for turning the work is driven from the same motor. The belt to the work cone runs at the

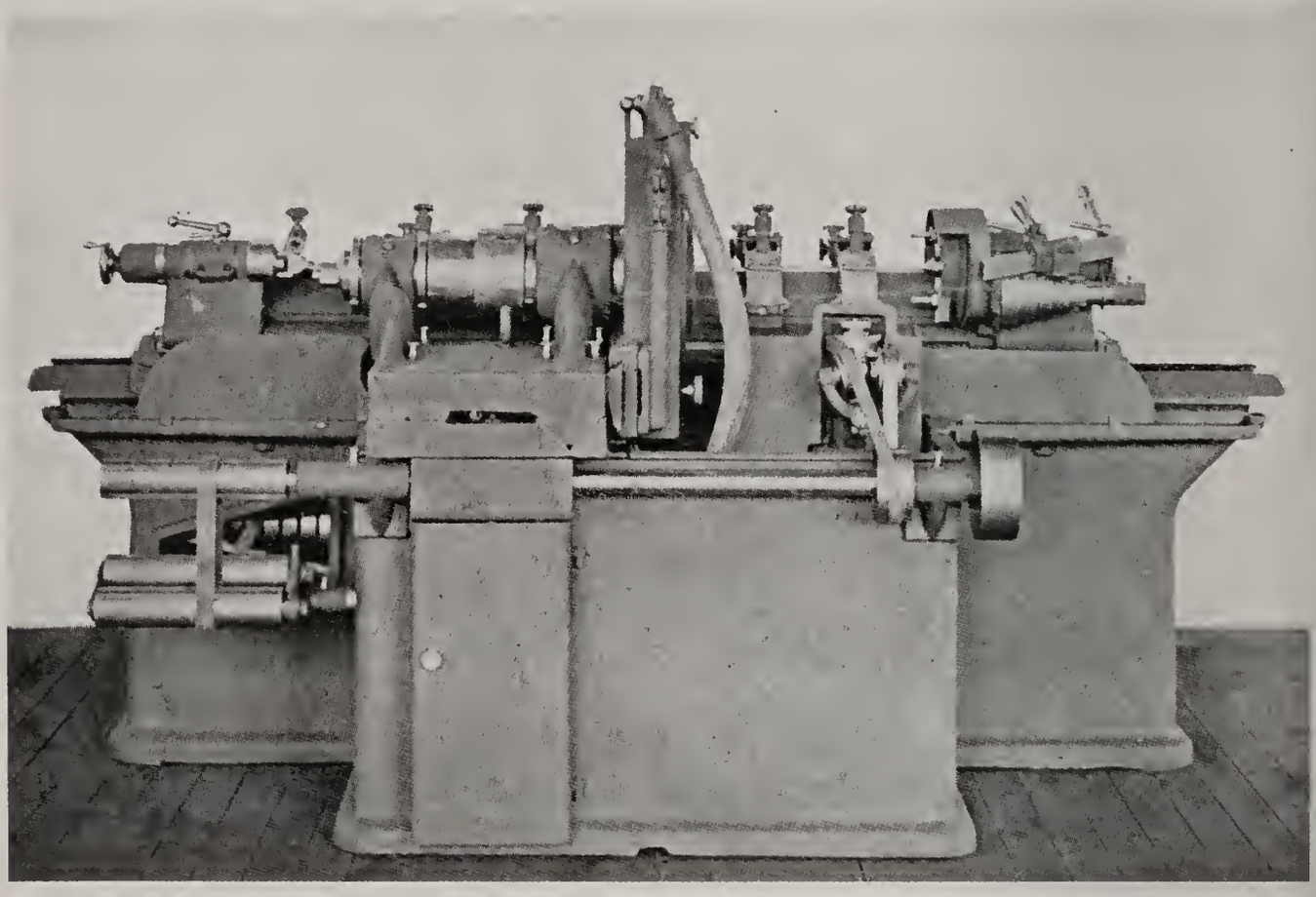

FIG. 105.

PLAIN GRINDING MACHINE—REAR VIEW.

The Norton Emery Wheel Co., Worcester, Mass.

top on a long drum to allow for the traverse of the table. As thus arranged the machine is self-contained and independent of any overhead connections. Such a drive leaves the way clear for a travelling crane above.

The work turns on dead centres and is steadied by numerous back rests arranged at intervals. The entire table carrying head and foot stocks and back rests is traversed automatically by the wheel, the latter always remaining in

the same position except as it is fed in to grind the proper size.

The makers claim that by this arrangement they secure greater steadiness and accuracy. It certainly has the advantage of keeping the cutting surface always in front of the operator as he stands at the centre of the machine. Provision is made on this, as on all similar machines, for grinding tapers by swivelling the top of the table so that the line of centres stands at an angle with the ways. This is

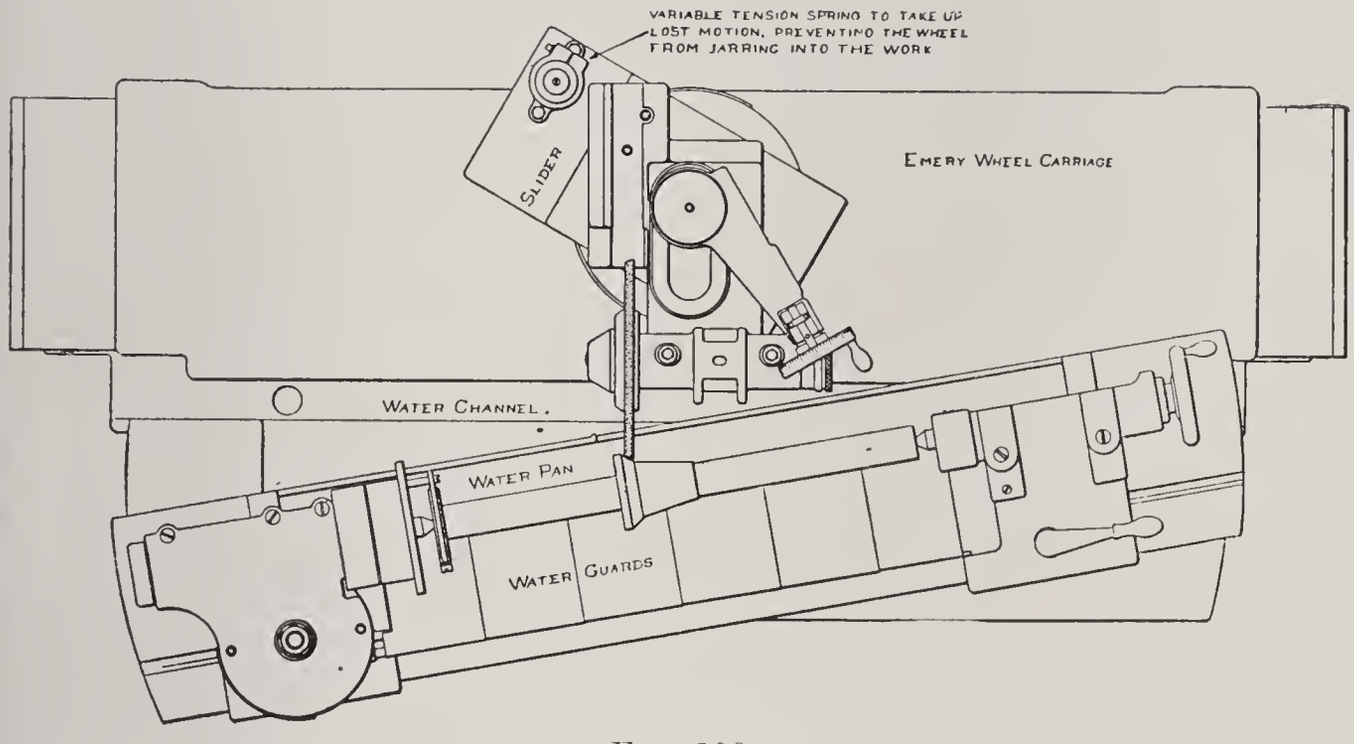
VARIABLE TENSION SPRING TO TAKE UP LOST MOTION, PREVENTING THE WHEEL FROM JARRING INTO THE WORK
SLIDER
EMERY WHEEL CARRIAGE
WATER CHANNEL
WATER PAN
WATER GUARDS

FIG. 106.

GRINDING TWO TAPERS.

The Landis Tool Co., Waynesboro', Pa.

the only swivelling possible with the plain machine, and it is this limitation which distinguishes it from the universal machine.

Both the traverse of the table and the cross feed of the wheel carriage can be made automatic. Either the speed of rotation of the work or the feed of the table can be varied independently without affecting the other. All the wheels and levers for controlling the machine are located in front near the centre of the machine. These grinding machines are made in sizes from 10×50 inches up to 18×168 inches, and arranged for either belt or electric drives.

140. Universal Grinding Machines.

Two views of a universal machine are given in Figs. 106 and 107 showing some of the details of the machine. While this particular make of machine has a stationary work table and a travelling wheel carriage, it is a peculiarity of the make and not of the type, and the plain machines made by the same firm have the same arrangement.

Perhaps the top view shown in Fig. 106 illustrates best the 'universality' of the grinder. The bearings of the grinding wheel are carried on a sort of compound rest having a swivelled connection to the carriage beneath. By means of a small micrometer wheel, shown in the illustration, motion can be given in the direction of the upper slide, either at right angles to the line of centres of the machine, or at any angle to which the slide may be swivelled. The milled screw head on one end of the wheel spindle can be used for giving an endwise adjustment to the wheel for face grinding, and is also graduated as a micrometer. This adjustable head for the wheel spindle is mounted upon a long and wide carriage that completely covers the ways on which it slides and protects them from dust and grit. The speed of traverse depends upon the width of wheel used, and is usually from one-half to three-fourths that width for each revolution of the work.

The head and tail stocks are located on a swivelling table, which can be seen in Fig. 106 as turned for grinding tapers. This table is graduated on the curved ends for degrees and for inches of taper per foot, and has a fine adjusting screw for precise measurements. The combination of the swivel on the wheel head and that on the table makes it possible to do work like that shown in the figure, where two tapers are being ground with one setting of the machine. Both head and tail stocks are bolted to a flat way on the table, and the lathe is protected from water and emery grit by

adjustable guards. As shown in Fig. 107, the headstock has a swivelling base to allow of grinding bevels and tapers in the chuck, and at greater angles than allowed by the table swivel. When used for grinding shafts on the dead centres the head is held exactly in line by a cotter pin, and the belt drives a loose pulley on the end of the spindle with a dog for turning the work, the spindle and the centre remaining stationary. When grinding work in the chuck, as shown in Fig. 107, the belt drives a pulley next to the head, which pulley is keyed to the spindle.

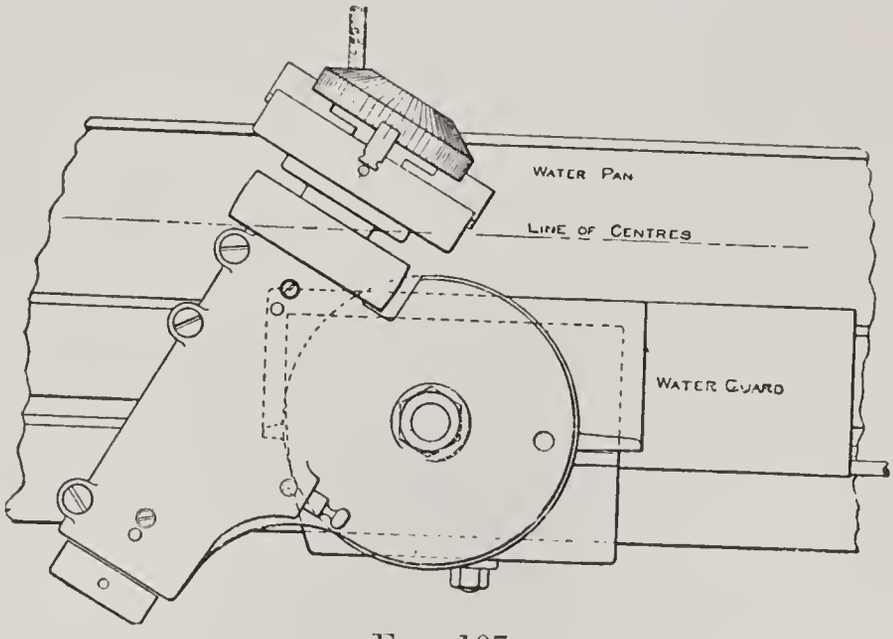

Fig. 107.

Grinding Taper in Chuck.

The Landis Tool Co., Waynesboro', Pa.

In this machine both wheel and work are driven from drums on the countershaft to allow for the necessary traverse motion. Stepped cones on the various countershafts make it possible to vary the relative speed of wheel, work, and feed motions to suit different materials and sizes.

The universal machine, while capable of doing the ordinary straight and taper work on spindles and shafts, is particularly adapted for finishing tools and other pieces having complicated shapes. A special attachment is provided for inside grinding, a small wheel being used at the end of a rather slender arbor. Such grinding, like internal milling, must be regarded as a necessary evil, and it is not expected that it can be done as rapidly or as satisfactorily as outside work.

Another universal machine is illustrated in Fig. 108. In general design this is similar to the machine shown in Fig. 105, since the wheel stand is stationary while the grinding is being done and the work table travels on ways.

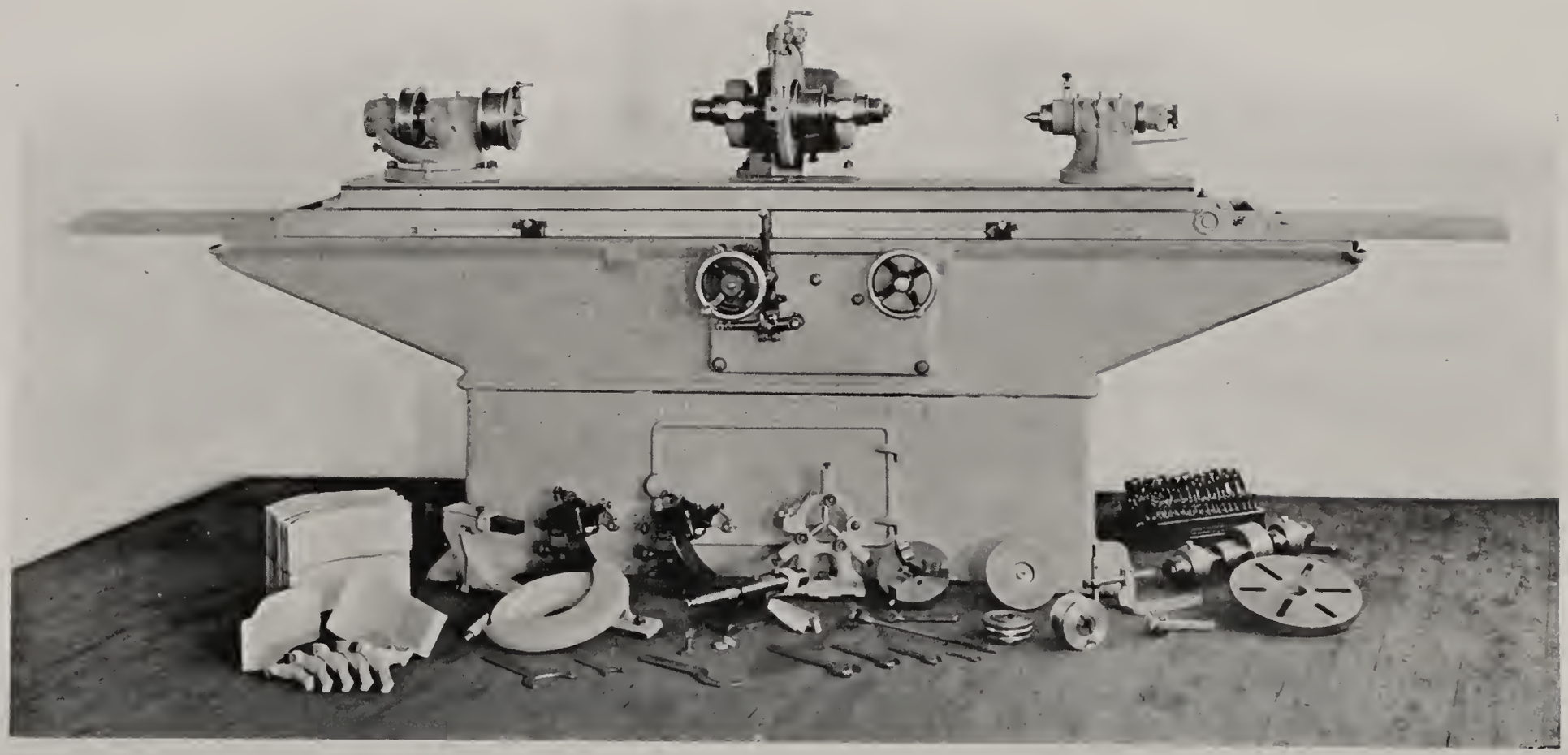

FIG. 108.

UNIVERSAL GRINDING MACHINE, 12 INS. × 60 INS.

The Brown and Sharpe Manufacturing Co., Providence, R.I.

Dogs on the table trip the reversing lever shown in front and can be adjusted for any stroke. The table swivels on its centre to any angle up to five degrees each way. The headstock swivels to any angle. The wheel stand swivels and has two motions besides—a transverse adjustment which can be set to thousandths of an inch, and the automatic cross-feed which operates at each reversal of the table. The latter can be adjusted so as to give from ·00025 to ·004 inch at each stroke. The machine can be arranged for either wet or dry grinding.

All grinding machines must possess three principal qualifications in order to be successful—viz. accuracy and freedom from lost motion in the guides; provision for thorough lubrication of all bearings; protection of all bearings from dust and grit, or from water, as the case may be. It may be assumed that these conditions have been met in the machines described in this chapter.

141. Tool Grinders.

One of the most common uses to which the grinding machine is put in the machine shop is that of grinding lathe and planer tools, and perhaps any grinding machine could be better spared than the one which performs this humble task. For such purposes the grinder has almost entirely superseded the grindstone, the latter being only used for thin-edged tools like those employed in the pattern shop.

In order to obtain the best results with lathe and planer tools, it is necessary that they should be sharp, and that they should be of the shape best adapted to the work to be done. These results are most readily obtained by having one man do all the grinding, both of new and old tools. Naturally the machine would be located in the tool-room, and the tools would be checked out to the men the same as other tools. This method also prevents the common practice of allowing high-priced men to waste their time in grinding

tools or in waiting for others to grind. There is no good reason why the machinist should sharpen his own lathe or planer tool, when reamers, milling cutters, etc., are sharpened in the tool-room. According to this system, when a workman finds that his tool is dull he immediately returns it to the tool-room and receives another which is sharp and of the same shape as the first.

It is equally important that the tool-grinding machine should be such as will readily duplicate the proper angles and shapes of the various tools, and that patterns should be kept in stock to preserve the record of shapes.

Fig. 109 illustrates a tool-grinding machine intended especially for tool-room use. The necessary patterns and data for grinding are sent with the machine. The grinding wheel has two cutting faces, conical in shape and making an angle of 90 degrees with each other. This shape gives more grinding surface, and is more convenient for grinding tools of various bevels, as well as for fine work in corners. As is well known, a plane surface is not suitable for grinding tools, since it readily glazes and overheats the tool. The wheel spindle has unusually long bearings, which are well protected from water and grit. A small crane is provided for convenience in handling the wheel. The machine is intended for wet grinding, and an abundant supply of water is provided. If the machine is used on high-speed steels the water is omitted.

The tool holder is universal, having all the motions necessary for the grinding of any tool for lathe, planer, or slotter, internal or external. The tool is aligned and clamped by the base as it would be in the lathe or planer. The holder or chuck can be rotated around a horizontal axis parallel with the shank of the tool and set to within a tenth of a degree. The frame holding the chuck can in a similar manner be rotated about a vertical axis passing near the point of the tool. The frame is carried on two slide rests 90 degrees apart, or parallel to two grinding faces. Finally,

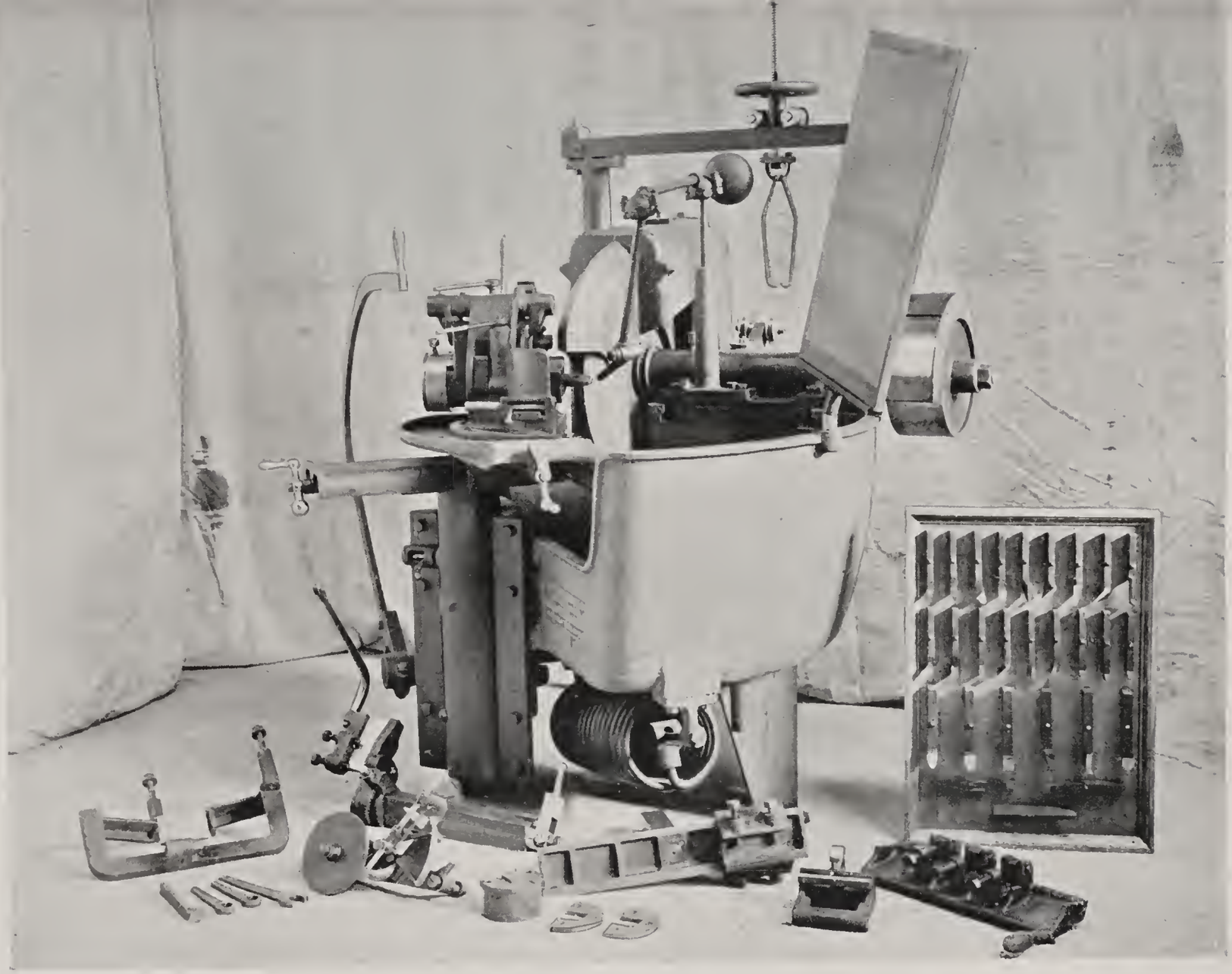

Fig. 109.

NO. 1 UNIVERSAL TOOL GRINDER.

William Sellers and Co., Philadelphia, Pa.

the whole combination is carried by a vertical slide counterbalanced by a spring. The tool, being properly clamped to the chuck and adjusted to the desired angle vertically and horizontally, can be then moved accurately in two horizontal lines and one vertical line, so as to give the necessary traverse for producing the surface required. Tables of angles accompany the machine, and enable the operator to reproduce any of the pattern tools. Of course the list sent can be varied or added to as the judgment of the foreman may dictate.

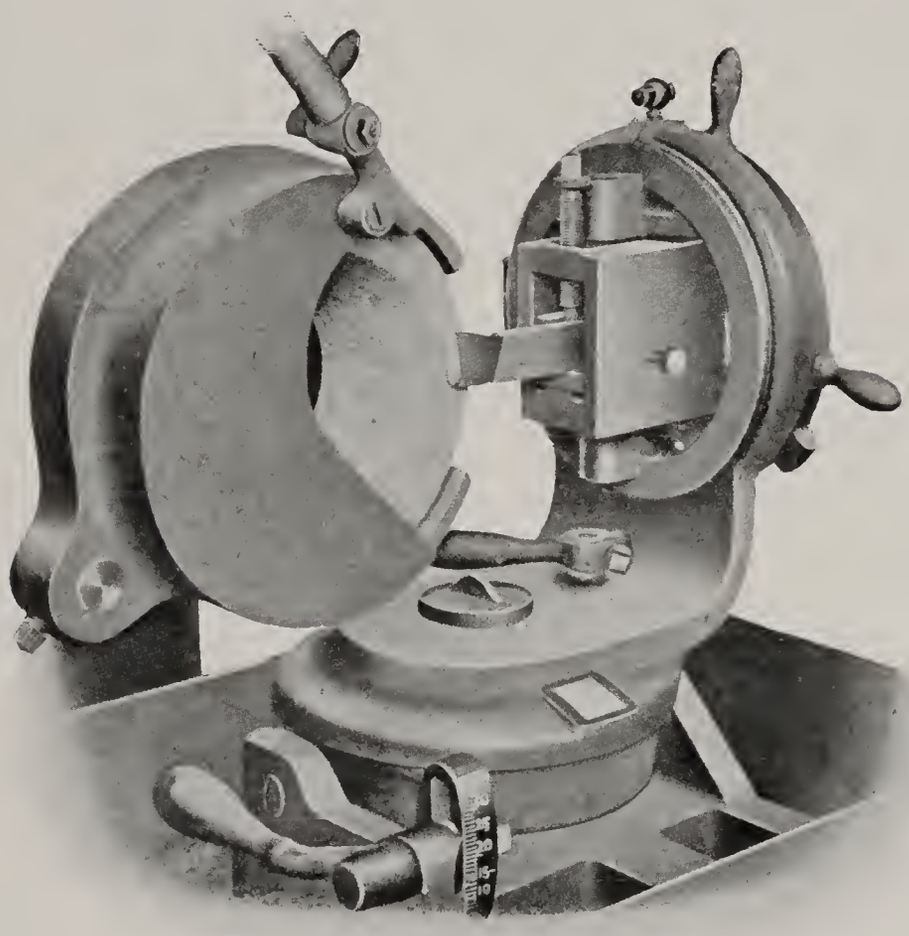

Fig. 110.

Gisholt Tool Holder.

A great variety of lathe tools can be ground on this machine, and the same rule applies to tools for other machines. Special chucks and holders are furnished, and others may be had to order. The machine shown in Fig. 109 is capable of handling stock up to $2 \times 2\frac{1}{2}$ inches. A smaller machine limited to stock $2 \times 1\frac{1}{2}$ inches is simpler in construction and carries a cylindrical wheel. The larger machine can also be used for duplicating curved shapes by the employment of a form plate and guide rolls. These machines are also particularly useful in grinding thread tools of various shapes where accuracy is absolutely necessary.

Another tool-grinding machine is made by the Gisholt Company, Madison, Wis., and differs in many particulars

from that just described. Fig. 110 is an elevation of the tool holder, and shows the various adjustments. The chuck in the centre holds the shank of the tool by three set screws. For grinding bent tools the chuck may be turned 30 degrees either side of the centre line to bring the face of tool parallel to grinding surface of wheel, the angle being shown by a graduated circle just below the chuck. The circular frame holding the chuck may be rotated about a horizontal axis parallel to shank of tool through an entire circle for grinding sides and top of tool. The circular base of tool holder may be turned about a vertical axis passing near point of tool through 320 degrees. The entire tool holder may be tipped about a horizontal axis through an angle of 15 degrees to allow for clearance on thread tools. The graduated vertical circle at the bottom shows this angle. With this machine, as with the one just described, it is possible to grind any face at any angle, and to duplicate pattern tools indefinitely.

142. Twist-Drill Grinders.

What has been said with regard to the grinding of lathe and planer tools in the tool room applies equally well to twist-drill grinding. The constant use of the twist drill on all kinds of work, and the fact that a drill poorly ground will spoil work, are two potent arguments for the use of the drill-grinding machine in every shop.

It is practically impossible to grind a twist drill accurately by hand, while, in a properly designed machine, this may be done with ease. There are two principal requisites in twist-drill grinding, one that the two lips shall have the same length and inclination, the other that the clearance may be just enough for free cutting and no more. This last requirement can be met practically by grinding the surface of the lip in a cone whose axis is in a different plane from that of the drill as shown in Fig. 111. When so ground, the lip will have a clearance increasing slightly back of the edge and also being

greater near the point. If, then, the drill in being ground is oscillated about this inclined axis, the correct shape will be produced.

Either wet or dry grinders may be used; if water is employed it is better to have the drill ground with the point lower than the shank, and apply the water to drill rather than the wheel, to avoid spattering. This is done in the case of all water grinders of the type shown in Fig. 112. This

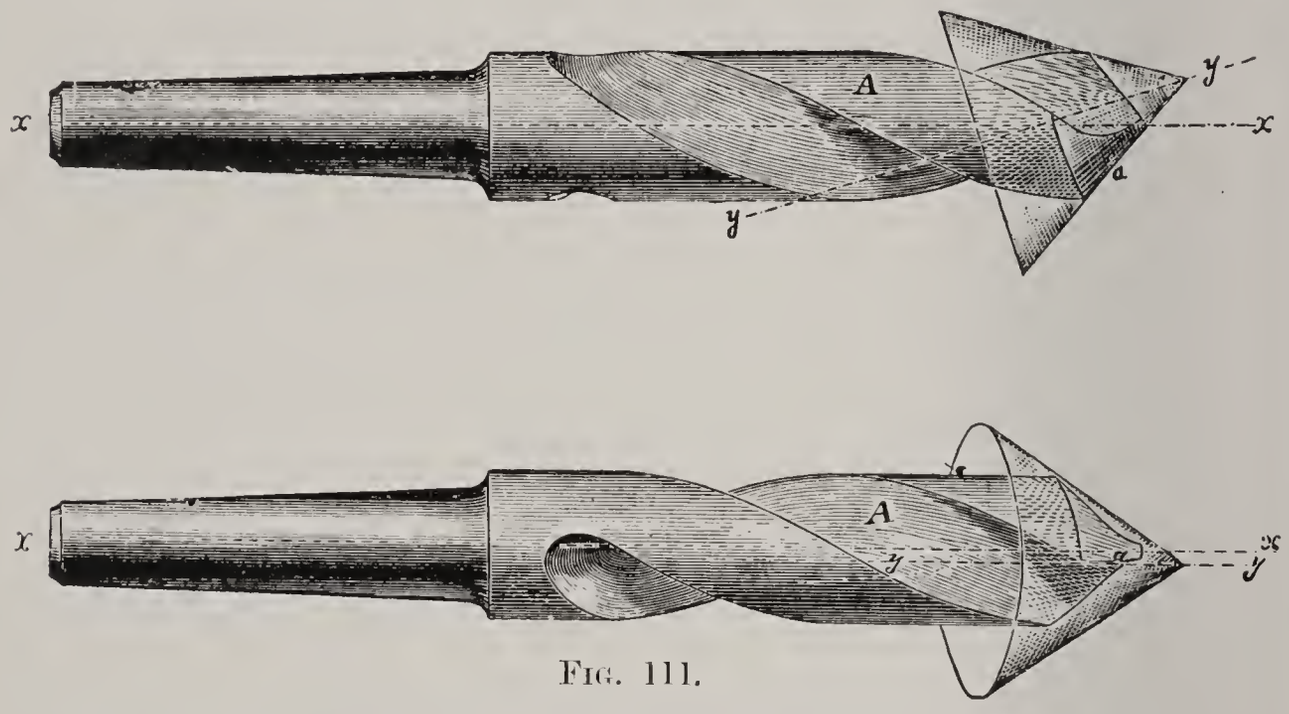

FIG. 111.

METHOD OF GRINDING DRILLS.

William Sellers and Co., Philadelphia.

figure shows a so-called universal grinding machine adapted to grinding all styles of drills, having two cutting lips, and capable of giving any desired angle to the lips from 75 to 140 degrees, and any desired clearance. A ring wheel is used, mounted on a cast-iron face plate, and the drill is ground against the annular face. As the drill surface is convex there will be line contact and no danger of glazing. The drill is held by two V-shaped rests some distance apart, so as to give the mean axis of drill and allow for any slight irregularities. An adjustable stop regulates the longitudinal position of drill, and a steel rest bears against the lip which is being ground and determines its proper position. The lip stands in approximately a vertical position, and a raising or

lowering of the holder changes the lip angle without disturbing any of the other adjustments. The motion of the drill in grinding consists of a rocking about the inclined axis under the holder and a slight perpendicular movement. The combination of these two gives a helicoidal shape to the lip surface, similar to the surface of the cut, but having the necessary clearance. The clearance can be changed by rotating a nut at the bottom, thereby shifting the axis.

The hand-wheel at the side pulls the holder back from the wheel when a new drill is placed in position. The horizontal handle near this turns the holder about a horizontal axis and moves the drill back and forth over the face of the wheels.

A calliper attachment on the holder enables the operator to set the machine for any size of drill. The combination of movements described makes it possible to grind the correct surface on the lip of a drill of any size, at any desired angle and any clearance within reasonable limits. Other grinding machines by the same makers have the adjustments of the universal machine just described, with the exception of that which varies the angle between the lips, the standard included angle of 118 degrees having been adopted. The machines are arranged for electric or air drive, if desired, and can be had for either wet or dry grinding.

The Yankee drill grinder differs from the one just described in one very important particular—viz. the angle between the axis of oscillation and the axis of the drill.

In Figures 111 and 112 the angle is shown as considerably less than 90 degrees ; in fact, as about half that included between the edge of the lip and the axis of the drill. On the other hand, in the Yankee grinder this angle is 90 degrees, and the axis of oscillation is beyond the plane of the wheel. This gives an inverted cone as the surface of the lip, and materially changes the ratio of the clearance angles. Opinions are divided as to which is the correct angle, but the weight of evidence seems to favour the small angle. One

large firm of twist-drill manufacturers gives as the results of its experiments that the best ratio of the clearances for

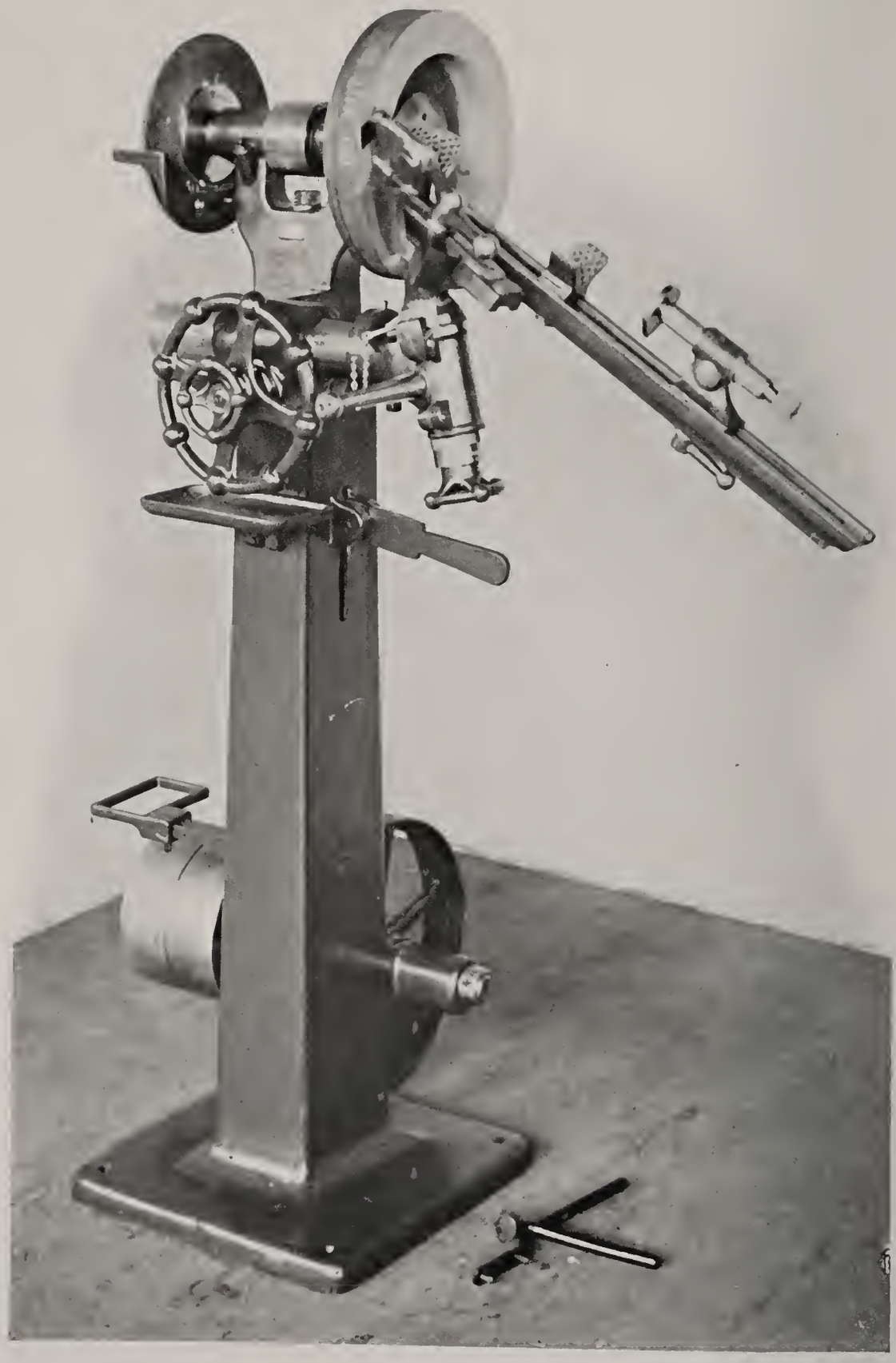

FIG. 112.

THE WORCESTER UNIVERSAL TWIST DRILL GRINDER.

The Washburn Shops, Worcester, Mass.

good cutting power and endurance is obtained by using the smaller angle, as in Fig. 112.

William Sellers and Company of Philadelphia, from whose catalogue Fig. 111 has been reproduced, manufacture a drill grinder embodying the principles which have been explained in this chapter, and also having a drill-pointing attachment which grinds small grooves either side of the point, and thus improves the cutting edge there. Twist-drill grinders are frequently run by electric motors, and two systems are in vogue. On one the motor is on the spindle of the machine and direct-connected; in the other, the motor is located in the base of the machine and connected with the wheel spindle by a belt. The disadvantage of this latter method is, of course, the use of the belt. The advantage is the possibility of running both motors and wheel at the most economical speed. A machine of this class with the motor at the top is also perhaps a trifle top-heavy.

143. Cutter and Reamer Grinders.

The increasing use of milling cutters, and the demand for standard sizes in all classes of reamers, have made grinding machines for this style of cutting tool almost a necessity.

Most of the machines for this class of work are of the so-called universal type, as shown in Fig. 113. These machines will grind almost any shape of cutter, reamer, mandrel, or collar that it is possible to imagine. The wheel usually employed is of the hollow cylindrical or hollow conical type, which gives a narrow cutting edge and a straight clearance, and can be used on a large variety of shapes.

For plain work the thin disc wheel, if of sufficiently large diameter, gives good results. Fig. 113 shows the head of a universal grinder as used for sharpening the teeth of a large mill. In this case a wheel is used as large as will conveniently clear the next tooth, so as to grind a clearance having as little concavity as possible. The wheel cuts up on the tooth, and the latter is held by hand against the rest underneath. The various adjustments may be readily seen

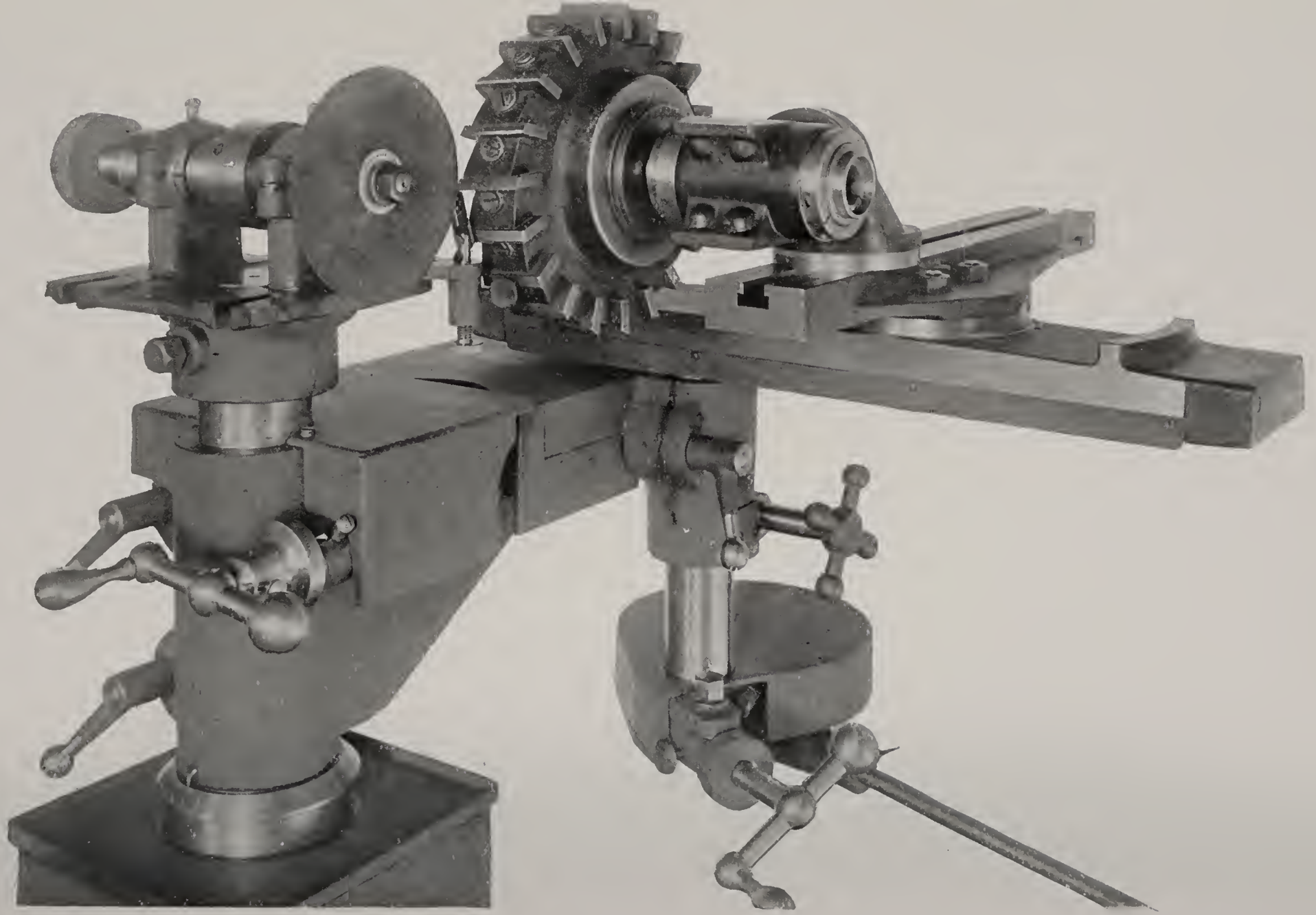

FIG. 113.

UNIVERSAL CUTTER AND TOOL GRINDER.

in the figure. The wheel spindle has two speeds, and is provided with a vertical adjustment for regulating the belt tension, and to make it possible to use endless belts. The table of the machine is carried on a knee, which can be swung entirely around the column and thus bring the wheel into any desired relation to the work. A cross-slide on this knee is operated by a hand crank having a micrometer attachment and serves to feed the work to and from the wheel. The table can also be raised or lowered by a rack-and-pinion arrangement, thus securing the necessary clearance. The table can be swivelled on the slide underneath, and the latter has a traverse movement for feeding the work, which may be operated either by a wheel or by a lever. In addition to all this, the head, which holds work not ground on centres, can be swivelled in both vertical and horizontal planes. All of the swivelling adjustments are provided with graduated circles and the straight ones with micrometer collars. It is possible with such a machine to present the work at any angle to the wheel, and thus to grind either flat, cylindrical, or conical surfaces.

Some of the applications of a universal machine such as described are found in sharpening milling cutters, gear cutters, and reamers of every description, in grinding mandrels and spindles either straight or taper, and in finishing collars and gauges inside and out. A small grooved pulley on the work spindle makes it possible to grind work on dead centres when necessary.

In a small way such a machine covers the entire field of surface and cylindrical grinding, and is a very useful tool in shops making fine machine parts.

The emery-wheel head of the machine just described is a good example of this class of spindle and bearings. Both bearings are adjustable for wear, are long in proportion to length of spindle, and are protected by dust caps. Two ends are provided for wheels, one end usually carrying a disc and the other a cup wheel. In Fig. 114 is shown another universal grinder, differing widely in detail from the last. The table and slides of this machine are swivelled to the top of

the column and have a bearing circle of large diameter graduated to degrees. A sleeve inside this circle gives a vertical adjustment for the wheel head, the latter being raised or lowered by the graduated hand-wheel at the right of the column. It will be seen that the working parts of the machine can thus be revolved around the wheel head as a

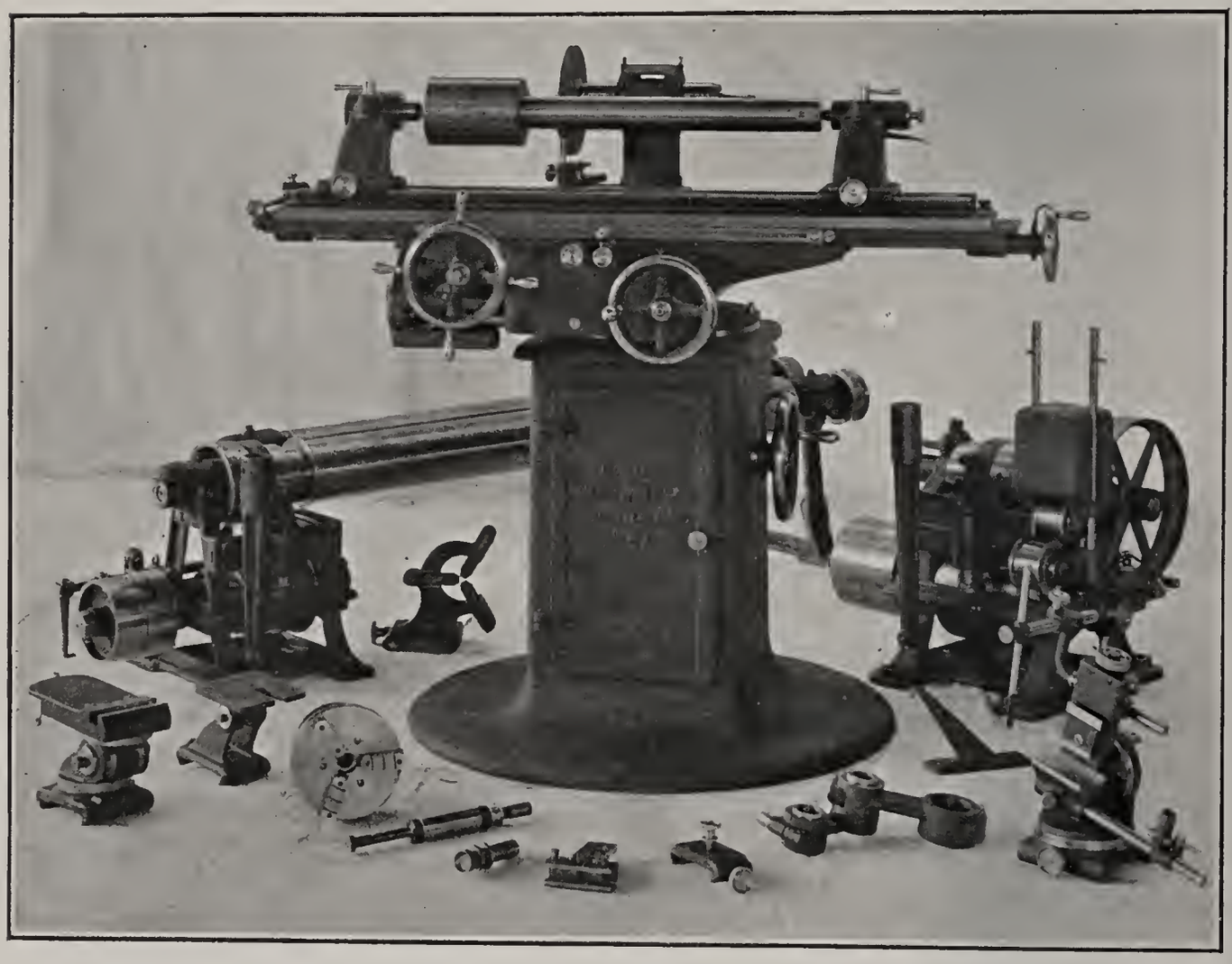

FIG. 114.

NO. 2 UNIVERSAL TOOL AND CUTTER GRINDER.

The Norton Emery Wheel Co., Worcester, Mass.

centre, to bring the work at the proper angle with the wheel. Above this swivel or turn-table is a cross-slide operated by the hand-wheel in front, which has micrometer graduations. The traverse of the table is above the cross-slide, and several feeds are provided; a rapid hand feed controlled by the pilot wheel in front, a slow feed or micrometer adjustment operated by the small wheel at the right, and an automatic feed driven by gearing underneath the left end.

The upper part of the table is swivelled for grinding

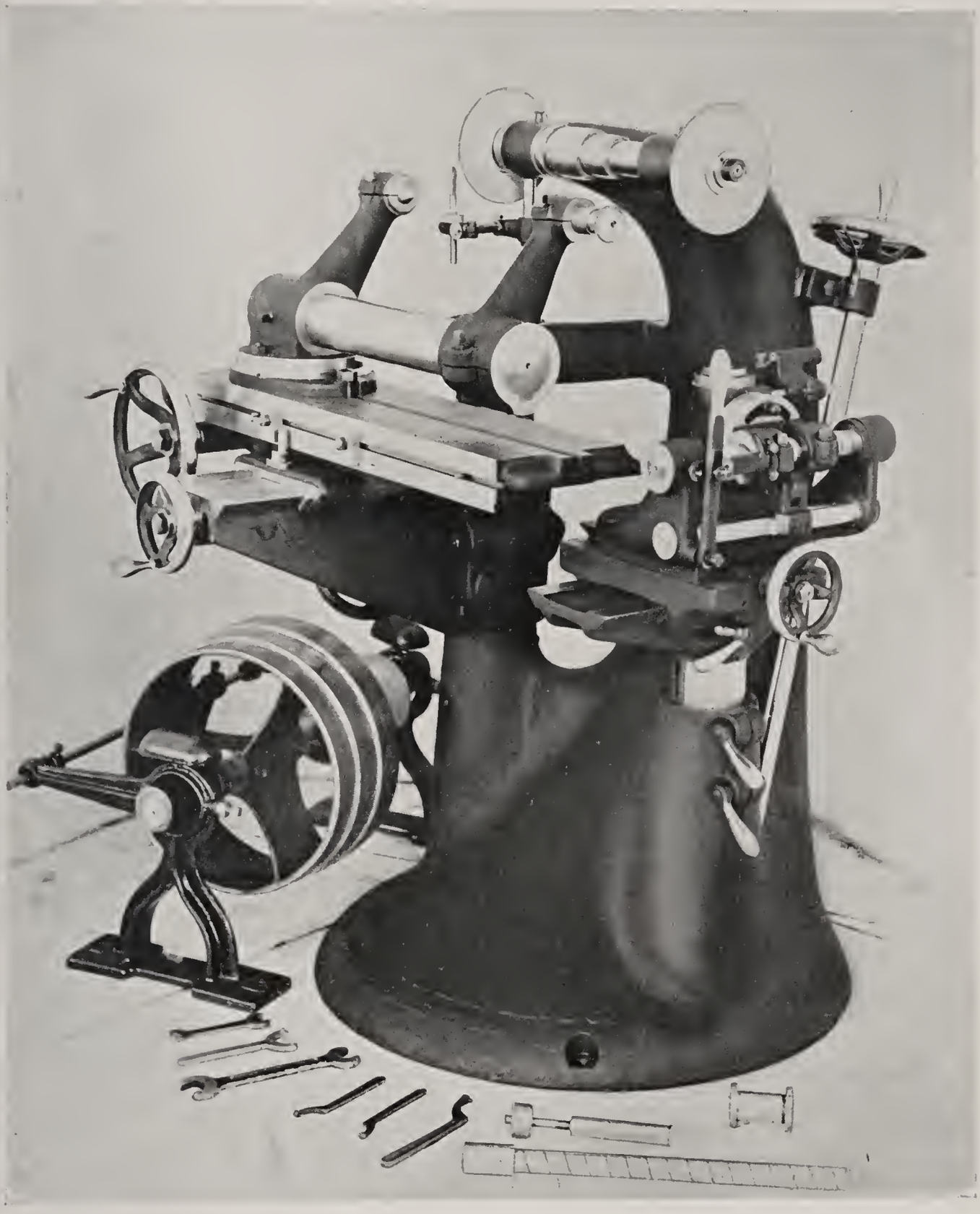

FIG. 115.

14-INCH CUTTER AND REAMER GRINDER.

The Becker-Brainard Milling Machine Co., Hyde Park, Mass.

tapers, and various heads and vices with swivelling connections are provided for grinding at various angles.

A four-speed countershaft accompanies each machine. As is usual, provision is made for revolving the work with a belt when grinding arbors and mandrels on dead centres. The next machine, Fig. 115, is intended especially for sharpening cutters and reamers, and is simpler in construction than the universal machines. The frame which supports the wheel spindle also carries two columns for the work carriages, one of the latter being intended for peripheral grinding, and the other for end grinding. Both carriages can be swivelled on the supporting columns, and both have vertical adjustments, cross feed and longitudinal traverse. The heads, carrying the centres or chucks, can be swivelled on the table for taper work.

The use of separate carriages for the two kinds of grinding mentioned simplifies somewhat the problem of setting the work and does away with some special attachments.

144. Emery Wheels.

The shapes of wheel used on the machines described in this chapter vary with the nature of the work, but one general principle governs the selection—viz. to have a narrow cutting surface on the wheel, as this ensures face cutting and prevents glazing. The disc grinder is an apparent exception to this rule; but even in these, the use of a corrugated surface has increased the cutting capacity.

The shapes most used are: (1) the thin disc cutting with its edge; (2) the ring wheel, cutting on the narrow annular face; (3) the cup wheel, of rather a saucer shape, and cutting on the thin edges. Emery wheels in this country are graded in two ways; first, according to the fineness of the grain, and second, according to the hardness of the bonding material or the texture.

The fineness of the grain is shown by numbers indicating the number of meshes per inch of the sieve or screen through which the grains of emery would pass. Thus, a grade-40

wheel would be one made of emery whose grains would pass through a 40-mesh sieve.

As to hardness, wheels are usually graded as medium, hard, soft, very soft, and very hard, the grades being denoted by letters. Unfortunately, different firms use different letters, so that it is necessary to have the firm's list or catalogue, in ordering intelligently.

One firm of wheel makers use all the letters of the alphabet to denote the different grades, beginning with A as extremely soft, and ending with Z as extremely hard.

For use on steel cutters and small tools, the makers generally recommend a fine grain, medium or soft wheel. If the wheel is too hard it will glaze, while, if too soft, it loses its shape and size too rapidly. There has been considerable discussion of late with regard to the safe speed of emery wheels, and some litigation has resulted from accidents occurring in service. Experiments made by the writer and reported in the *Transactions* of the American Society of Mechanical Engineers for the year 1903, show that emery wheels ranging from 10 to 60 size of grain, and of various degrees of hardness, are entirely safe at speeds of 5000 to 6000 feet per minute, the bursting speed varying from 11,500 to 19,200 feet per minute. These were disc wheels, and it is apparent that cup or ring wheels would need to be more carefully handled, and should be safeguarded by chucks or face plates, unless run at a lower speed.

CHAPTER X

PUNCHING AND SHEARING MACHINERY

145. Pressure Machines.

Machines which shape or cut metal by direct pressure on dies, belong rather to sheet-metal works, such as tank and boiler shops, than to the general machine shop. As it is the intention to limit the present treatise to a consideration of those machines which find a place in the general shop, only such machines will be illustrated or described in this chapter.

These are naturally divided into two classes, punching machines and shearing machines. The two functions are much the same, require the same frame and mechanism, and are frequently combined in one machine. The principal elements of such machines are—(1) the frame; (2) the pressure mechanism; (3) the clutches; (4) the driving mechanism; (5) the punches and dies.

146. The Frame.

The open-side or G frame is in general use, since it allows a greater range of work to be handled, and at the same time can be made rigid enough to stand the stresses which come upon it. Fig. 116 illustrates clearly the forms adopted by one firm of manufacturers, and shows the gradual increase in strength of back as the depth of throat becomes greater.

The double machines consist of two single machines placed

back to back, and driven by one train of gears so as to economise space. In such cases one of the machines is usually for punching, and the other for shearing. For very wide work, two of this kind of frames can be placed side by side, and some distance apart, like the housings of a planer. The shear blades extend from one frame to the other, and the work is fed between, making what is called a gate shear. Fig. 117 shows a large single machine of the open-side type. This shear has a depth of 60 inches from centre of cut to back of throat, and is capable of punching a $2\frac{1}{4}$-inch hole in

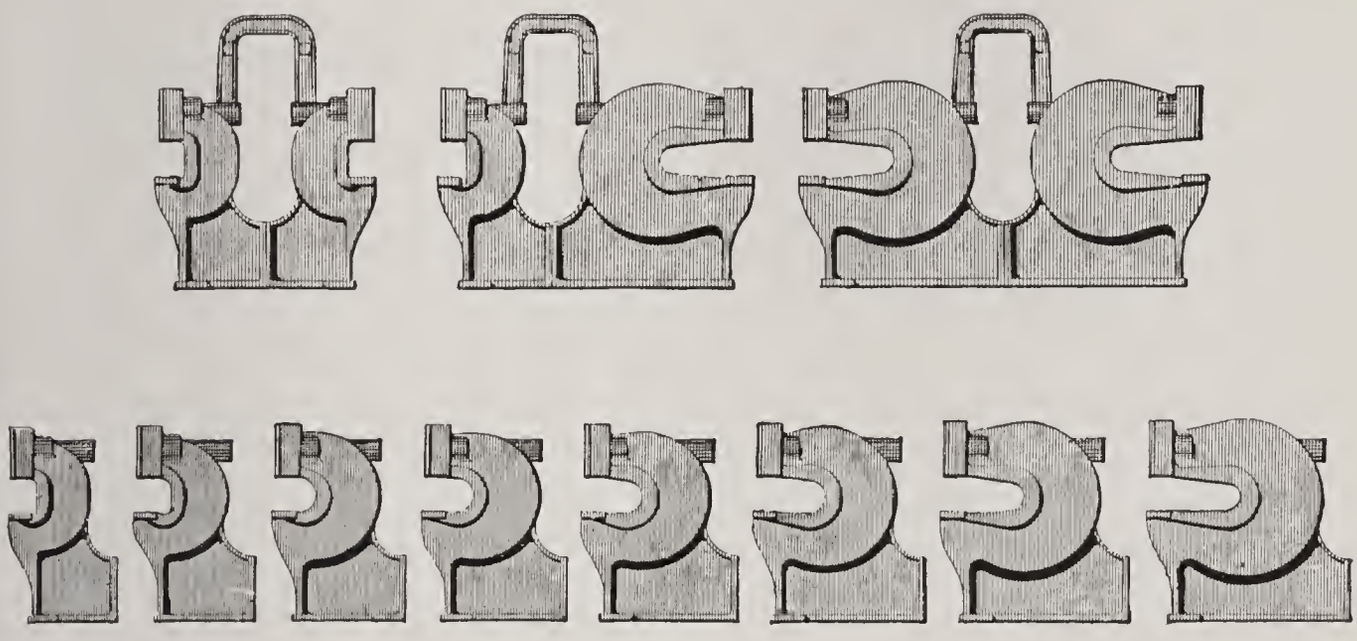

Fig. 116.

The Long and Allstatter Co., Hamilton, Ohio.

$1\frac{1}{4}$-inch iron, or shearing a bar of flat iron $1\frac{1}{4} \times 8$ inches. The general design and appearance of this machine are admirable.

The closed or H frame is little used for the jobbing or general class of machine, on account of its limited range, but for special machinery, such as that employed for embossing and pressing sheet-metal forms, it is stronger and less clumsy than the open frame.

Frames may also be classified as horizontal, vertical or inclined, the position of the frame being governed by the shape of the work to be done. The horizontal type as shown

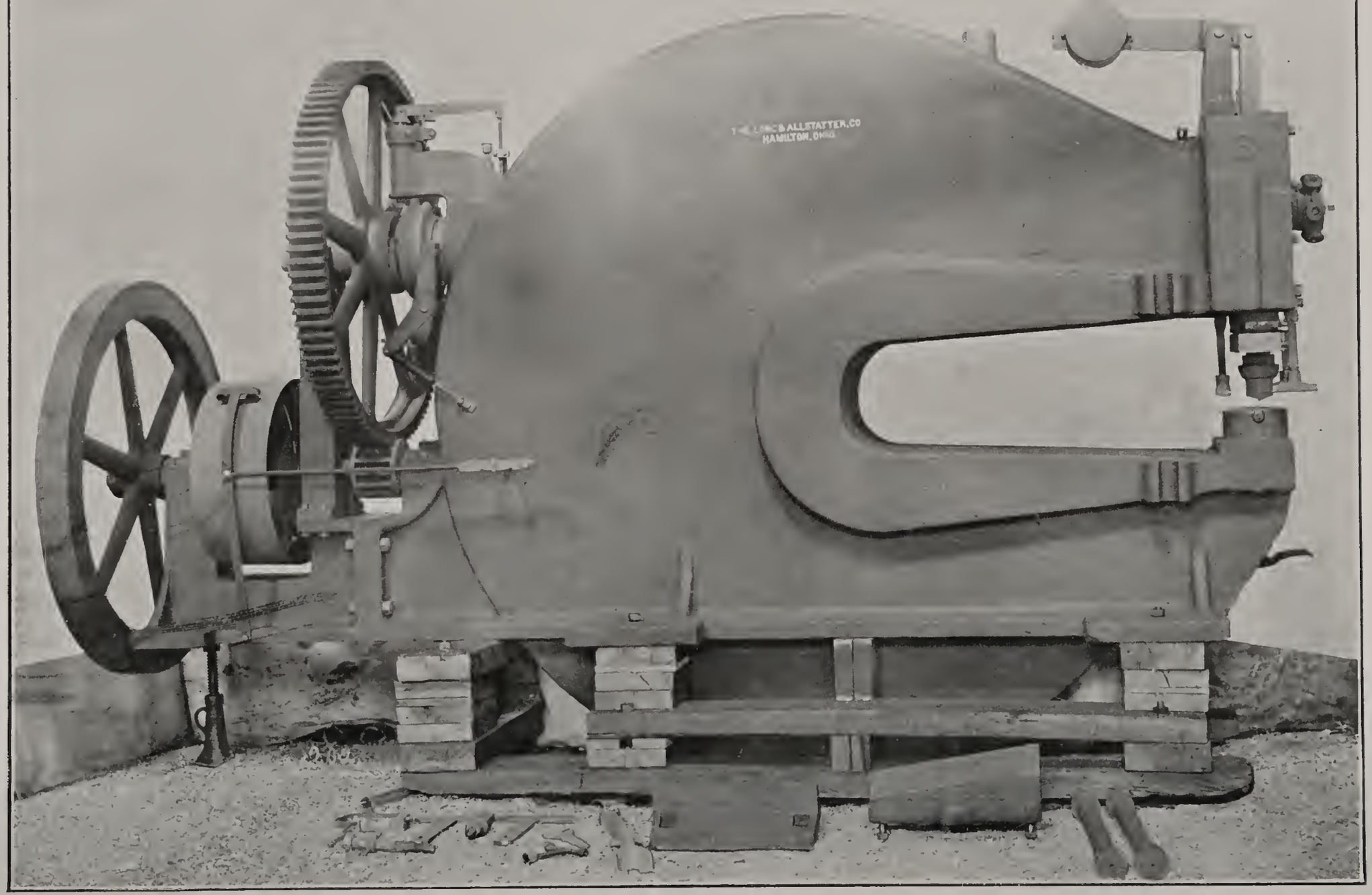

Fig. 117.

60-INCH PUNCHING PRESS

in Fig. 118 is well adapted for punching holes in flanges, while the body of the plate or bar is kept horizontal. In proportions and arrangement of driving machinery this form does not differ materially from the vertical ones just noticed. The inclined frame is generally made adjustable, so that it may be used either in a vertical or an inclined position.

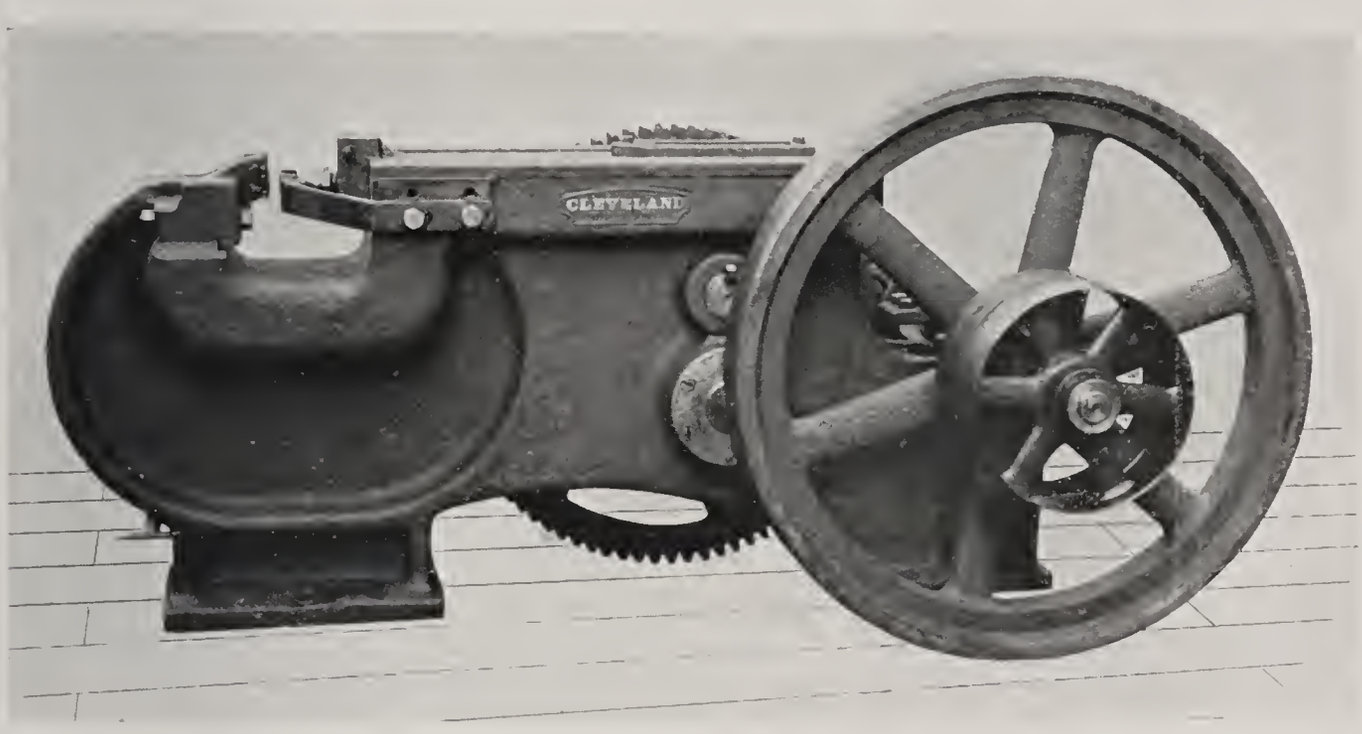

FIG. 118.

HORIZONTAL 10-INCH PUNCH.

The Cleveland Punch and Shear Works, Cleveland, Ohio.

These machines are employed for special rather than for general work.

147. Pressure Mechanism.

The pressure necessary to force the punch or die through the metal is obtained by the use of the eccentric, crank, cam, lever or toggle, as the case may be. Nearly all the machines illustrated and described in this chapter employ the crank and pitman form of motion, as it is simple and has the necessary increase of pressure at the end of the stroke. The lever machine such as shown in Fig. 119 is more common in iron and steel works than in the machine shop, and is obviously not adapted to punching. The toggle and cam motions are more often seen in presses for drawing sheet metal than in the shear or punch.

The adjustment of the punch or upper die is effected in most machines by a screw thread and nut. Fig. 120 shows the head of a press with crank and pitman connection, and a right and left thread with turn buckle.

Fig. 121 illustrates several of the methods of adjustment in common use. A shows plain right and left nuts with collar at centre for turning the screw, and U-shaped packing pieces between collar and nuts, making practically a solid

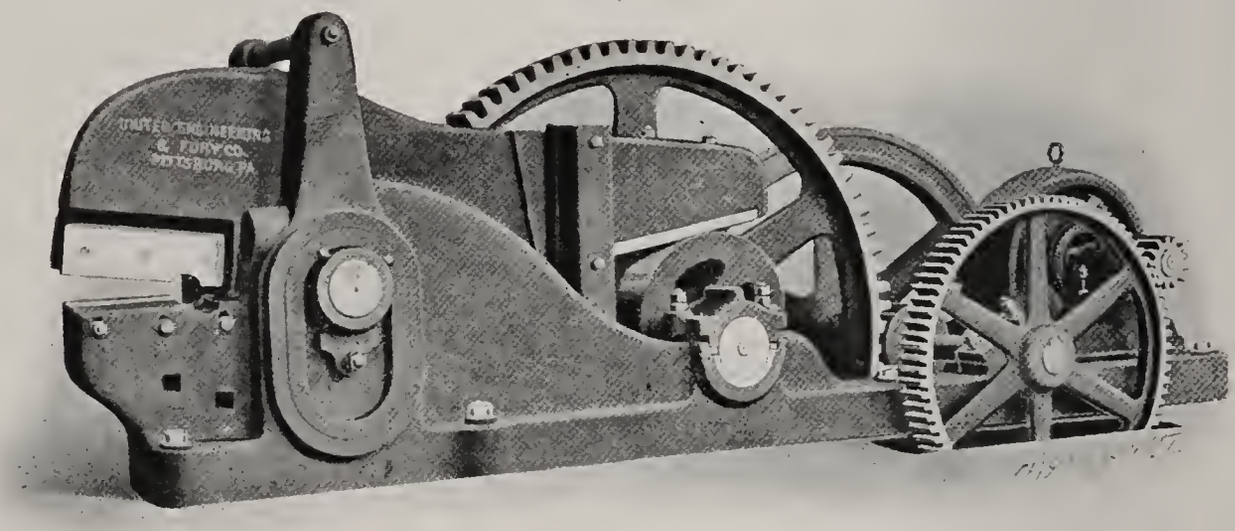

Fig. 119.

LEVER SHEAR—MOTOR DRIVEN—SHOWING KNIVES FOR CUTTING ROUNDS.

The United Engineering and Foundry Co., Pittsburg, Pa.

connection. B shows the introduction of a wedge for finer adjustment, while C represents right and left nuts with check nuts instead of packing pieces. Fig. 122 shows, on the other hand, the Stiles eccentric adjustment. As may be seen from the cut, the crank-pin bushing is eccentric, and by means of a gear and pinion can be revolved in its seat so as to change the length of the pitman. This arrangement makes a stiff connection without any screw threads. The lower end of the pitman in crank and eccentric connections usually bottoms directly in the plunger casting.

On all machines which are to be used for shearing it is important to have the plunger slides large and some distance apart, to resist the bending action due to the offset of

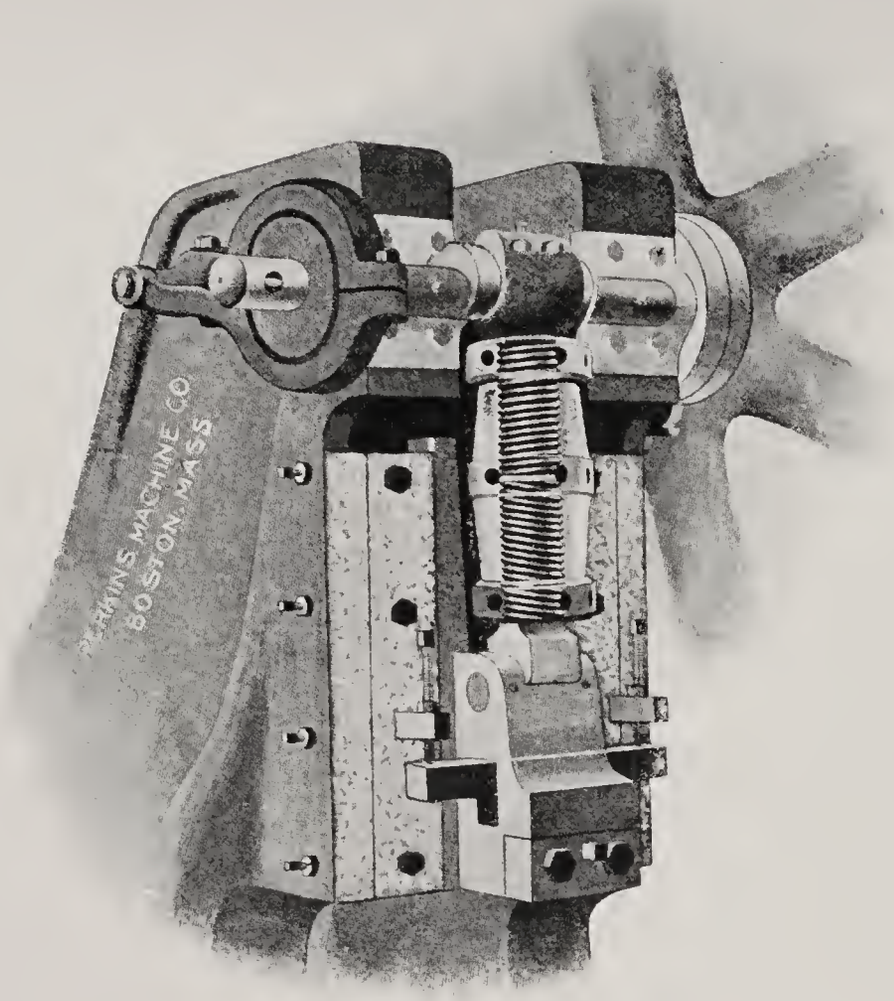

FIG. 120.

ADJUSTABLE PLUNGER.

The Perkins Machine Co., Boston, Mass.

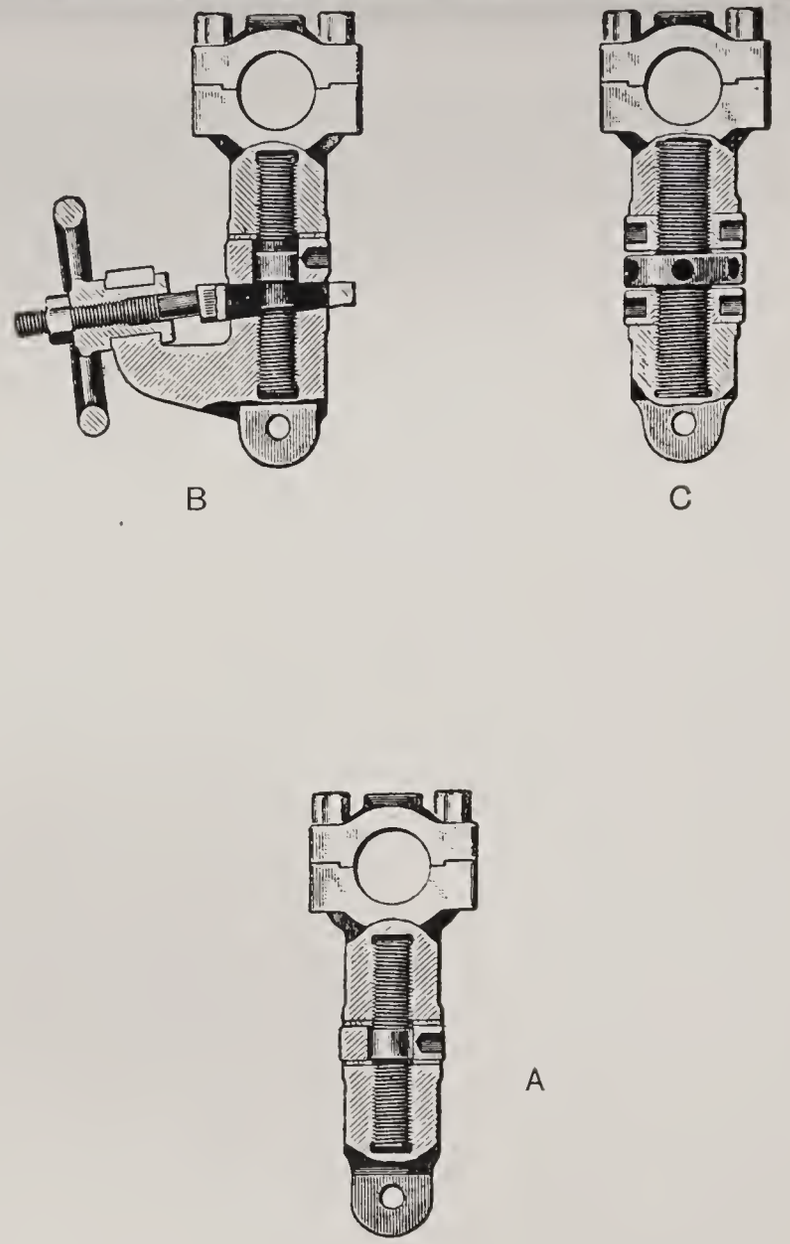

FIG. 121.

ADJUSTABLE PLUNGERS.

Waterbury-Farrel Foundry and Machinery Co., Waterbury, Conn.

the shear blades. One disadvantage of the lever shear is the fact that the pivot is not well situated to resist the side

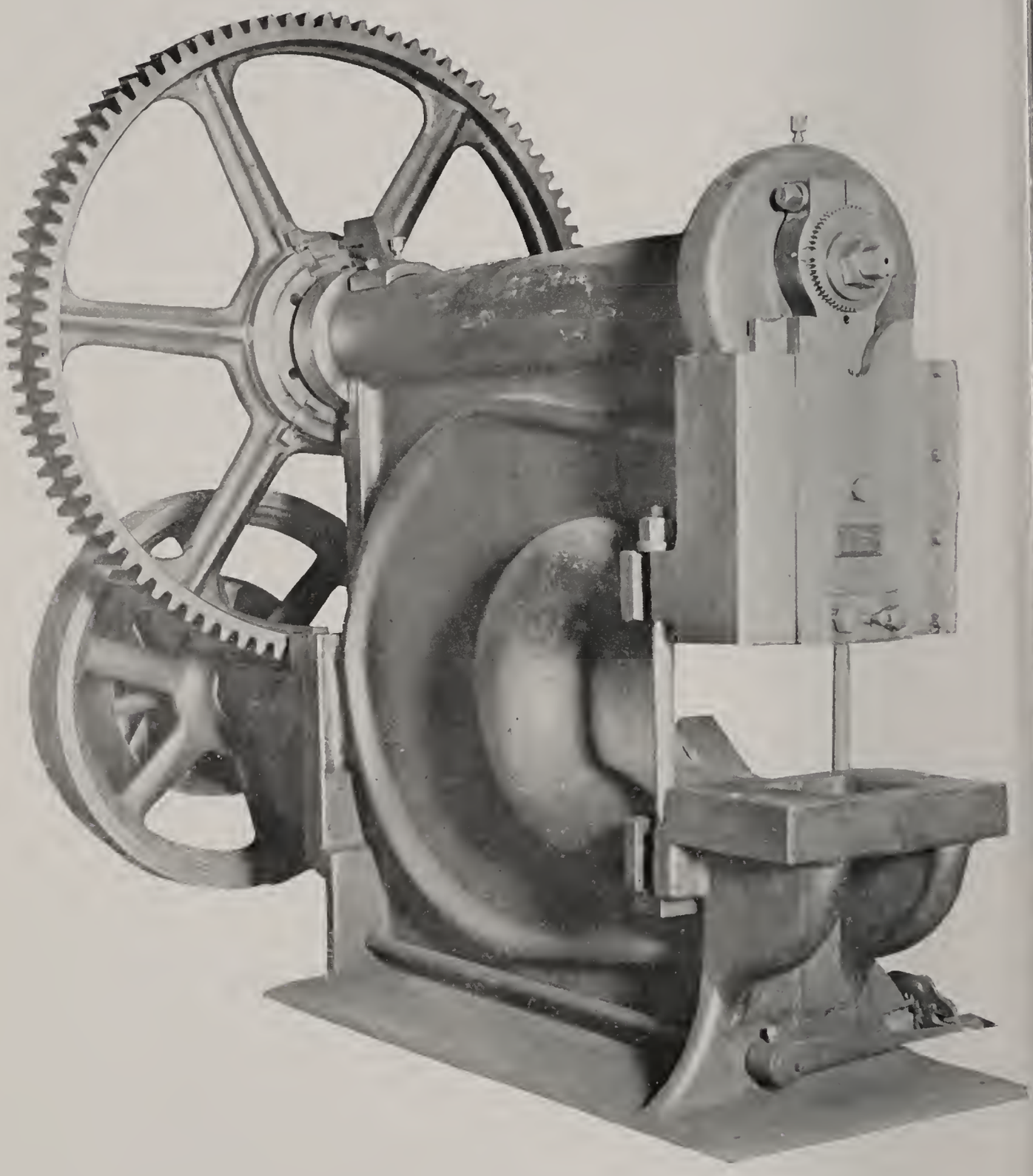

FIG. 122.

PUNCH WITH STAYED GAP.

E. W. Bliss and Co., Brooklyn, N.Y.

thrust of the blades. Fig. 119 shows double housings at the joint, and the lathe re-enforced by a double yoke. When a machine is used for punching or for die work it becomes

necessary to fit the slides carefully and provide means of adjustment for centring the dies.

148. The Disengaging Clutches.

Perhaps more ingenuity has been displayed in devising suitable arrangements for starting and stopping the motion

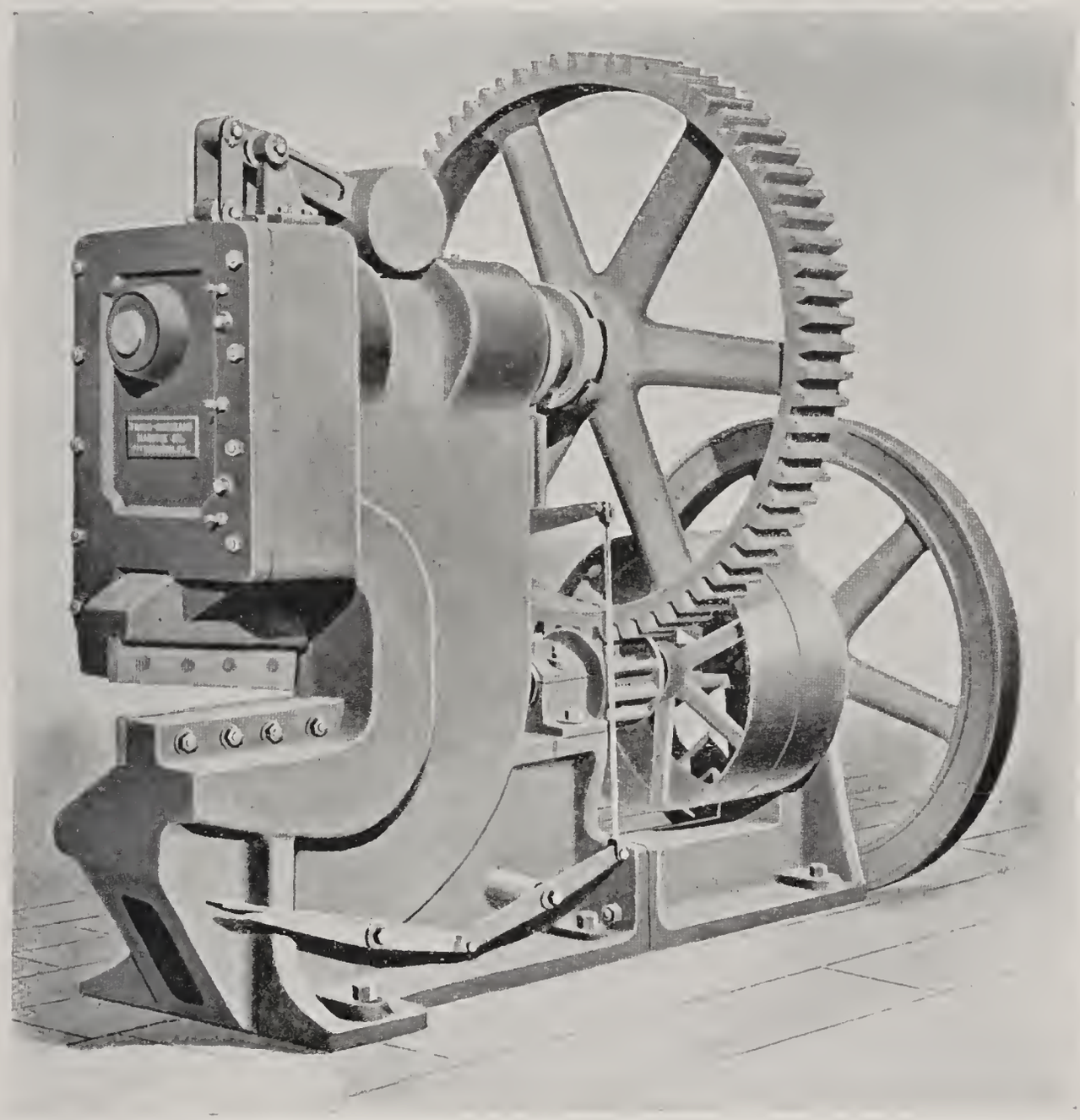

FIG. 123.

NO. 3 VERTICAL SHEAR, BELT DRIVEN.

The United Engineering and Foundry Co., Pittsburg, Pa.

of the plunger than in any other detail of power presses. The action of the shear or punch being so intermittent, and

the variation of energy exerted being so great, it is necessary to have a fly-wheel and to keep it running at speed. In practically all machines the fly-wheel runs loose at full speed when the machine is not cutting, and is engaged or disengaged by means of some form of clutch. In Fig. 123 a simple jaw clutch is used, engaging with the main driving gear. The machines made by E. W. Bliss and Co. have the rolling-pin friction clutch, engaging the whole length of hub close to the shaft. The advantage of the friction clutch is the almost instantaneous engagement of the wheel or gear when the lever is pressed.

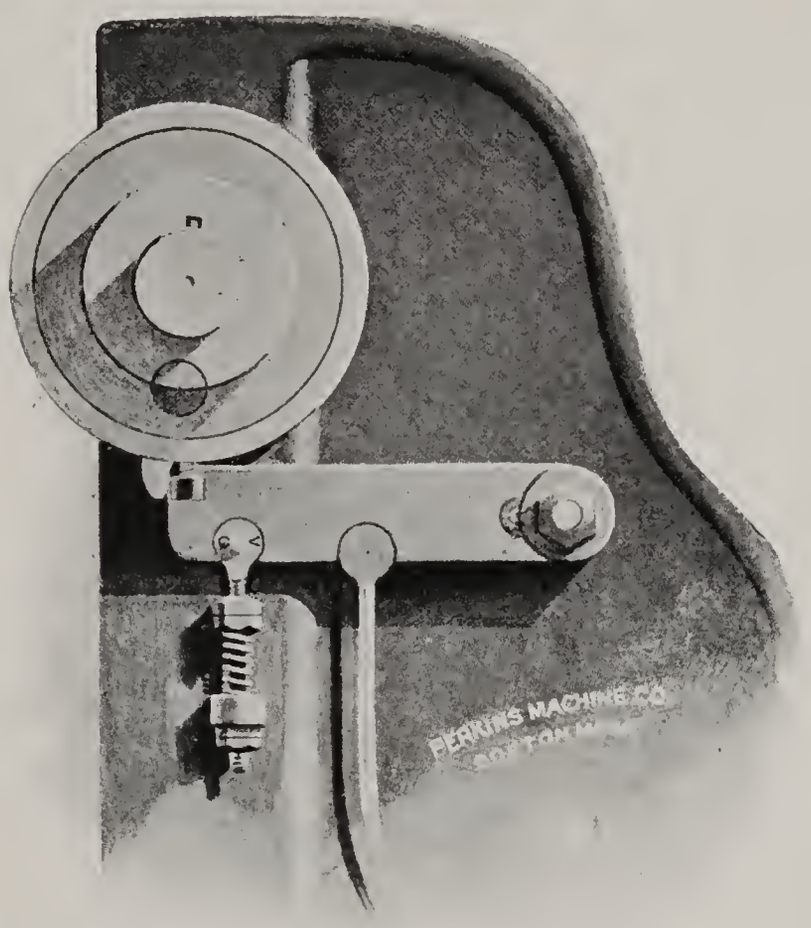

Fig. 124.

Perkins Automatic Clutch.

The Perkins Machine Co., Boston, Mass.

Fig. 124 shows a pin clutch of another type with the wheel removed. When the pin is in the position shown, the wheel runs loose on hub of collar. A partial rotation of pin causes it to engage with one of several recesses provided in hub of wheel. The starting lever is shown in the cut. All clutches on this class of machinery are arranged to be partially automatic. That is, after being engaged by a pressure on the treadle, they release automatically when the pressure is removed and leave the plunger at the highest point. If the pressure on the treadle is not removed the machine continues to act. Some machines have an adjust-

able release cam or wiper, which can be so set as to disengage at any point in the revolution. On other machines a hand lever is used, by which the operator may stop the machine at any point in the stroke. A brake which is thrown on by the stopping mechanism is also an important adjunct of machines which run at a high speed. A continuous friction on one end of the crank shaft sometimes serves a similar purpose.

The punch illustrated in Fig. 125 has no clutch, and the shaft runs continuously, a 'gag' being used to start the motion of the plunger. This is pushed into position by the operator, and pulled back by a spring.

149. The Driving Mechanism.

The nature and the extent of the machinery for driving a power press depends upon the size and character of the machine. The smaller sizes have the fly-wheel on the crank shaft, and are driven directly by a belt or motor. The arrangement which is most common, and which is illustrated in nearly all the machines shown, is that of a countershaft, running at a comparatively high speed and carrying a fly-wheel, geared at a ratio of perhaps 6 or 8 to 1 with the crank shaft. In such cases the clutch usually engages with the larger gear on the crank shaft, although in some instances the clutch is on the countershaft. The service is so severe that unusual pains must be taken with the gear and pinion. The pinion should have the teeth shrouded at the ends, and a large pitch must be used. Some makers half shroud the teeth on both gear and pinion. Forged-steel crank shafts are quite generally employed, and the type of the frame used in vertical machines is favourable to long bearings. In presses and shears for heavy work double gearing is often resorted to, especially with motor drives, as in Fig. 119. Electrical driving is frequently used to advantage on these machines, particularly on those of large capacity.

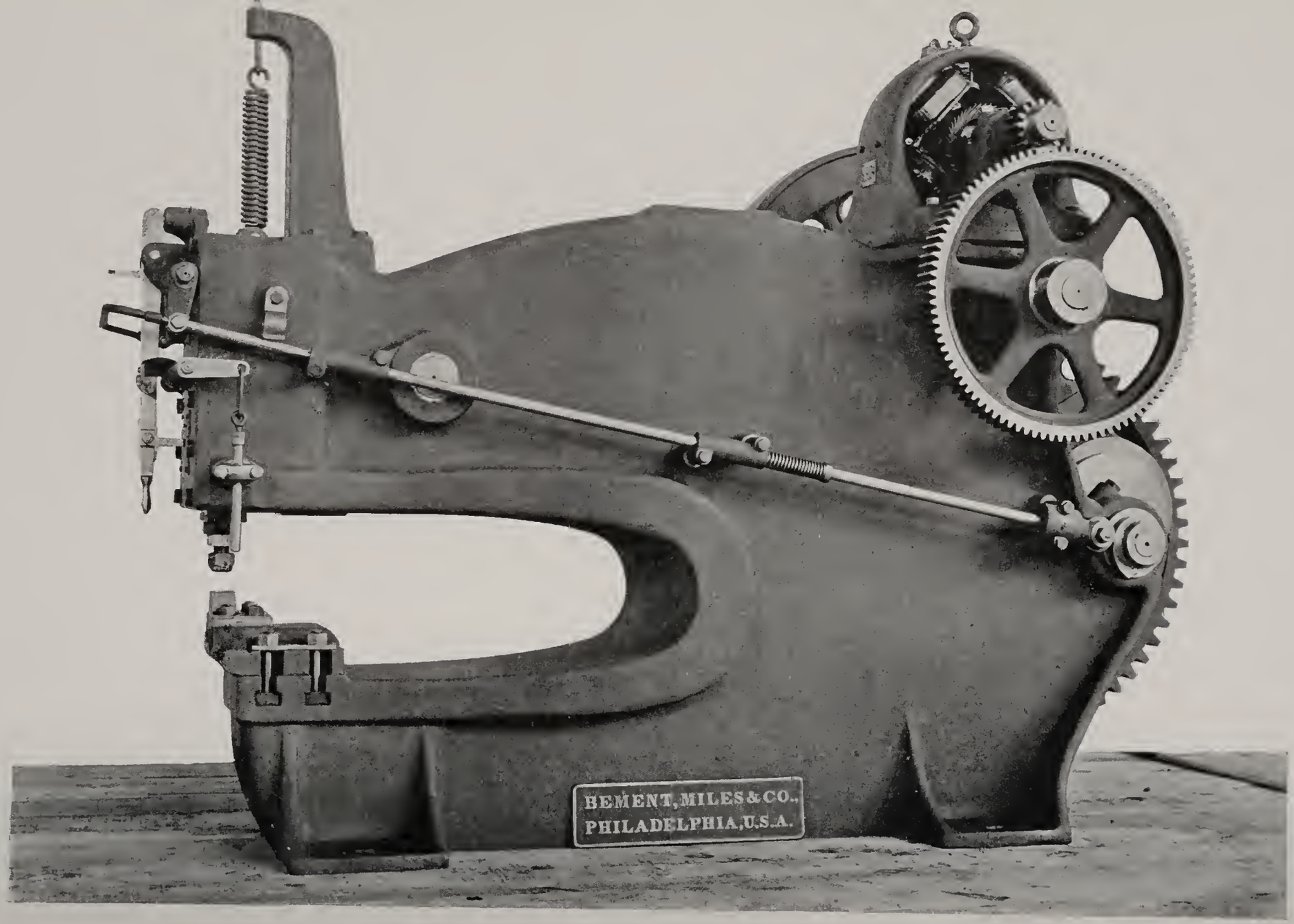

FIG. 125.

MOTOR-DRIVEN LEVER PUNCH.

Nearly all American manufacturers are now prepared to adapt their machines to the motor drive when asked, and the adaptation presents no particular difficulty.

150. The Tools.

The plungers of most machines are adapted to receive either punches and dies or shear blades, as the work may require. The punches and dies used are of a standard pattern, the punch being of the flat-end form with a centre point, and the die flat but slightly convex on top. Punches having a spiral cutting edge are manufactured for the trade, but, so far as is known, comparatively few are in use. Experiments made by the writer several years ago demonstrated the fact that spiral punches developed considerably less resistance in going through the metal and injured the plate less than the flat form.

The resistance offered to the spiral punch averaged more than 20 per cent. less than that of the flat form, and the loss of strength of the metal by punching averaged only 3 per cent. as against 7·5 per cent. for the ordinary punch. The penny-whistle form of punch also makes a shearing cut, and penetrates with less effort than the ordinary form. Users of punching machinery, who wish to do work beyond the ordinary capacity of the machine, can easily solve the problem in this way.

The vertical adjustment of the punch is effected by changing the length of pitman in the manner already described, while the two horizontal adjustments are made in the holders. The stripper should be made adjustable for different conditions. The shear blades can be set parallel to the frame of the machine for cutting, as shown in Fig. 123, or at right angles for splitting plates.

151. The Lever Shear.

This chapter would be incomplete without further reference to that useful and powerful tool, the alligator or lever

shear. The plain lever machine adapted for cutting only is illustrated in Fig. 119, which shows a large machine of this class with a motor drive. As may be readily seen from the illustration, this machine is operated by a cam on the main shaft, while the lever is steadied by rigid guides. A steel plate takes the thrust and sliding off the cam. These machines are also arranged to be driven by a crank on the main shaft and a short pitman taking a knuckle bearing on the tail of the lever. The main pin is fast in the lever and oscillates in the housings on either side.

The particular machine shown in the figure weighs, complete with 50 horse-power electric motor, 57,000 lbs., and is capable of cutting 4 × 4-inch or 5-inch round soft steel.

Fig. 125 shows a punching and shearing machine with the G type of frame, but driven by a lever and cam instead of the usual crank and pitman. The starting and stopping of the plunger is effected by a gag which is operated by a hand lever. The machine is double-geared, permitting the use of a relatively high-speed motor. The machine illustrated in the figure is capable of punching a $1\frac{1}{4}$-inch hole in a 1-inch plate, of shearing 1-inch plate, or of cutting 2-inch rounds.

CHAPTER XI

SCREW-CUTTING MACHINERY

152. In General.

VARIOUS methods of cutting threads, either external or internal, have already been noticed. The use of the engine lathe for this purpose is not as common a practice as formerly on account of the slow and expensive nature of the process.

Small machine screws and bolts are largely the product of the turret lathe or automatic screw machine, while longer screws, such as those for machine feeds, are often made by the milling thread cutter described in Chapter VIII.

After these are all accounted for, there still remain the larger and longer varieties of bolts used for fastenings, too big for the screw machine and not requiring the accurate but expensive finish given by the lathe or the thread milling machine.

Such are usually threaded with chasing dies in the bolt cutter. Machines for cutting threads on pipe such as is used for gas, steam, or water, hardly come into the category of machine shop appliances, since this work must usually be done by the steam fitter. We cannot well avoid the consideration of them, however, as they resemble the bolt-cutting machines so closely, the same machine being sometimes adapted to both operations.

They usually differ in the motions of the die and work, the bolt-cutting machine having a revolving die and stationary holder, while in pipe cutting the work itself is usually revolved.

153. The Die Head.

By far the most important element in the bolt cutter, and the one on which most care and thought have been bestowed by the designer, is the head for holding and adjusting the chasing dies. Figs. 126A and 126B illustrate a type of die head which has been in long and successful use. The barrel or body of the head is of cast iron, but has hardened steel

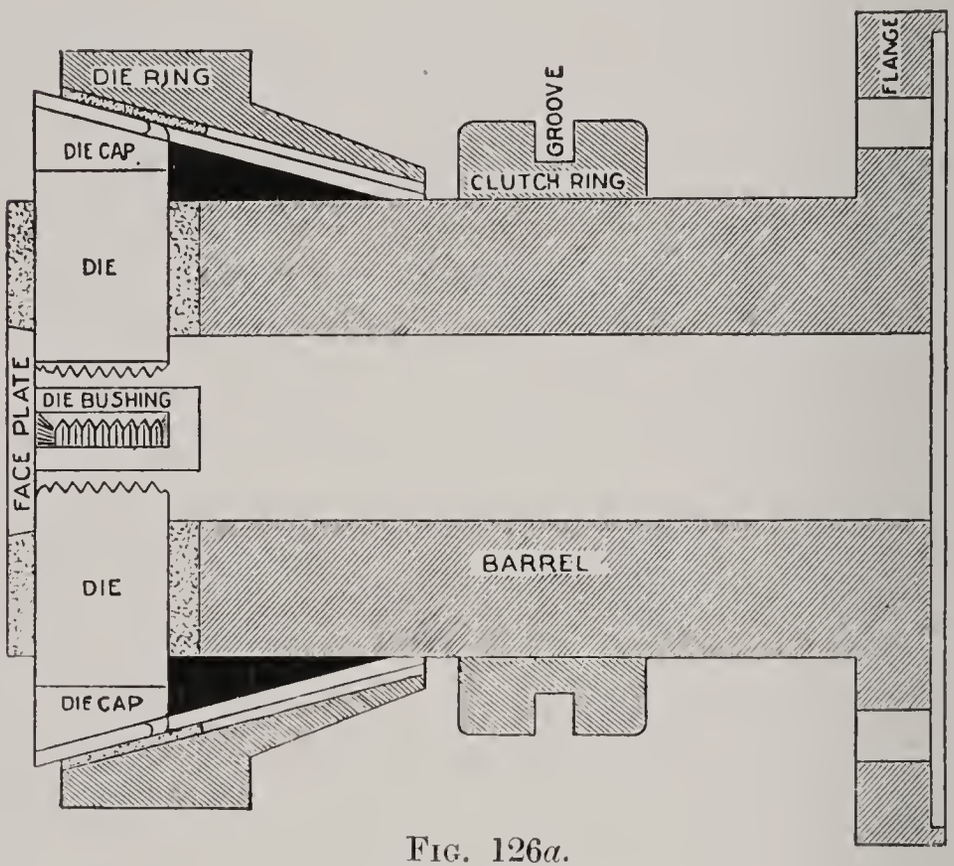

FIG. 126*a*.

THE ACME DIE HEAD.

The Acme Machinery Co., Cleveland, Ohio.

strips set lengthwise of its outer surface to take the wear of the die ring.

The dies, four in number, slide radially in slots in a face plate which is fastened to the front end of the barrel by screws. The outer ends of the dies are guided by die caps, and these latter have sloping tops which fit corresponding grooves in the die ring.

As the die ring slides forward or back on the barrel these sloping grooves move the dies in or out in a manner which may be readily understood from the figures.

The wearing surfaces are faced with hardened steel to reduce the wear to a minimum.

The die ring is moved by a rocking lever and link not shown in the cuts, and controlled by the movement of the

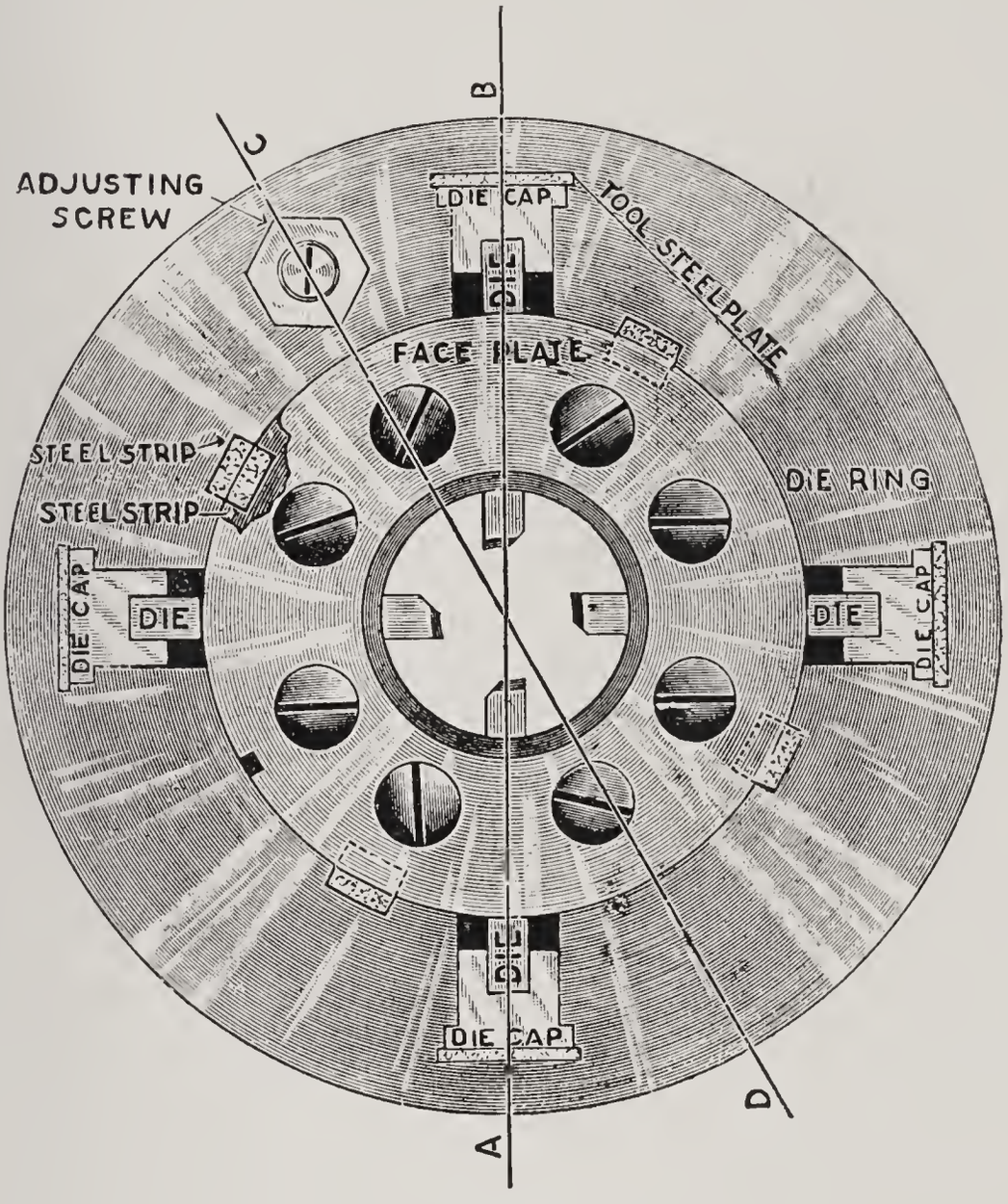

Fig. 126*b*.

THE ACME DIE HEAD, SHOWING HARDENING STEEL STRIPS IN BARREL AND DIE RING.

clutch ring on the barrel. An adjusting screw at the connection between the die ring and the link makes it possible to so set the combination as to give the exact size of cut desired.

A bronze ring fitting the groove in the clutch ring is connected with an automatic opening and closing device operated

by the machine itself. On the later machines of this make a separate adjusting screw renders it possible to open or close the dies for a roughing cut without disturbing the adjustment for a finishing cut.

In this machine the dies are radial, the cutting edge being slightly ahead of the centre, as seen in Fig. 126. The dies are reamed in position and cut by a master tap, which is slightly smaller than the bolt to be cut.

When the die is adjusted to size, the fact that the cutting edge is ahead of the centre will ensure the necessary clearance.

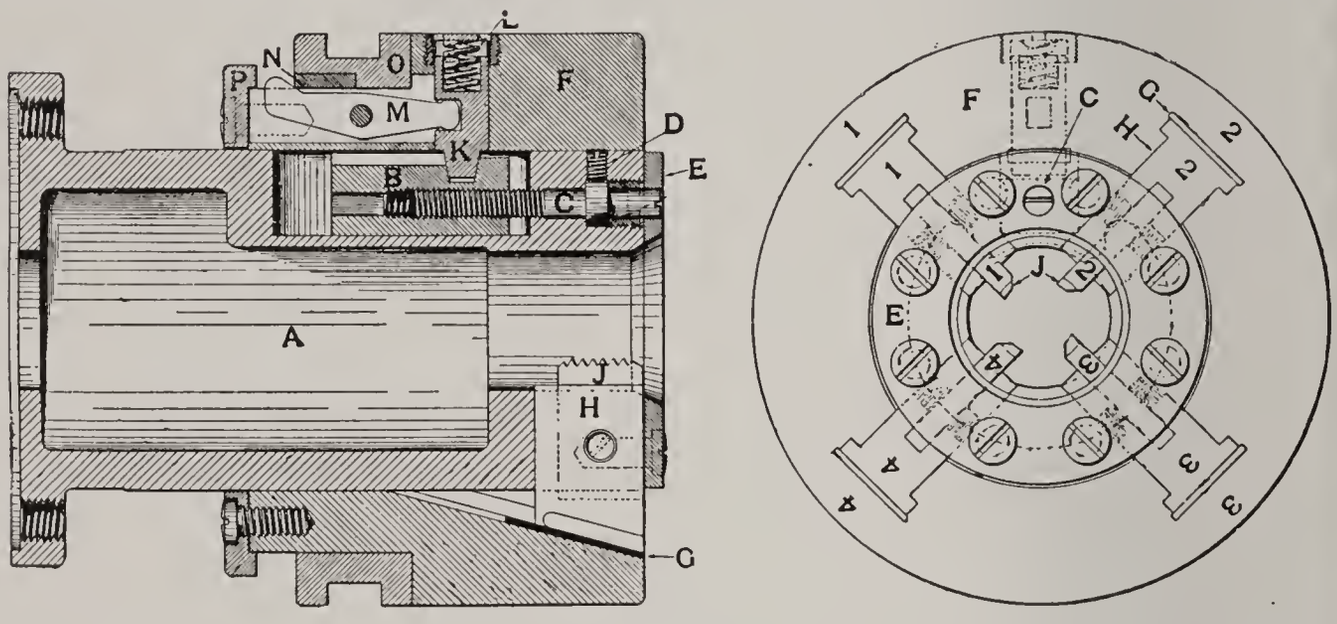

Fig. 127.

DETAIL OF THE STANDARD MORGAN DIE-HEAD.

The dies are then reamed with a taper reamer giving a throat at the entrance, and the heels of the dies are filed back to the centre line. Fig. 127 shows a die head of somewhat similar construction, there being the radial dies, the die caps, and die ring, as in the one just described.

The locking of the dies in the closed position is effected by the taper plunger K fitting in the adjustable bar B. The clutch-ring O lifts this plunger by means of the lever M during the back-lash interval, and then pulls back the die ring itself, opening the dies. The opening and closing can be performed automatically or by hand.

Fig. 128 illustrates an entirely different type of die and head. The teeth on the die, instead of being tapped or

hobbed in the usual way, are milled on the flat side, and the dies are set at such an angle in the head as to present the correct cutting edge.

They are set almost at a tangent to the circumference of the bolt, and are also inclined to the plane of rotation to correspond with the obliquity of the thread.

In other words, they correspond to the threading tool used in a lathe, and can be ground on the end indefinitely without changing the shape of the cutting edge.

The dies are hardened and tempered the whole length, so that they can be used until too short for further grinding. The grinding process is simpler than in the dies before described, and does not require as much expert skill. At the same time, the introduction of the straight in place of the curved clearance would not seem to be so favourable to endurance and to smooth cutting.

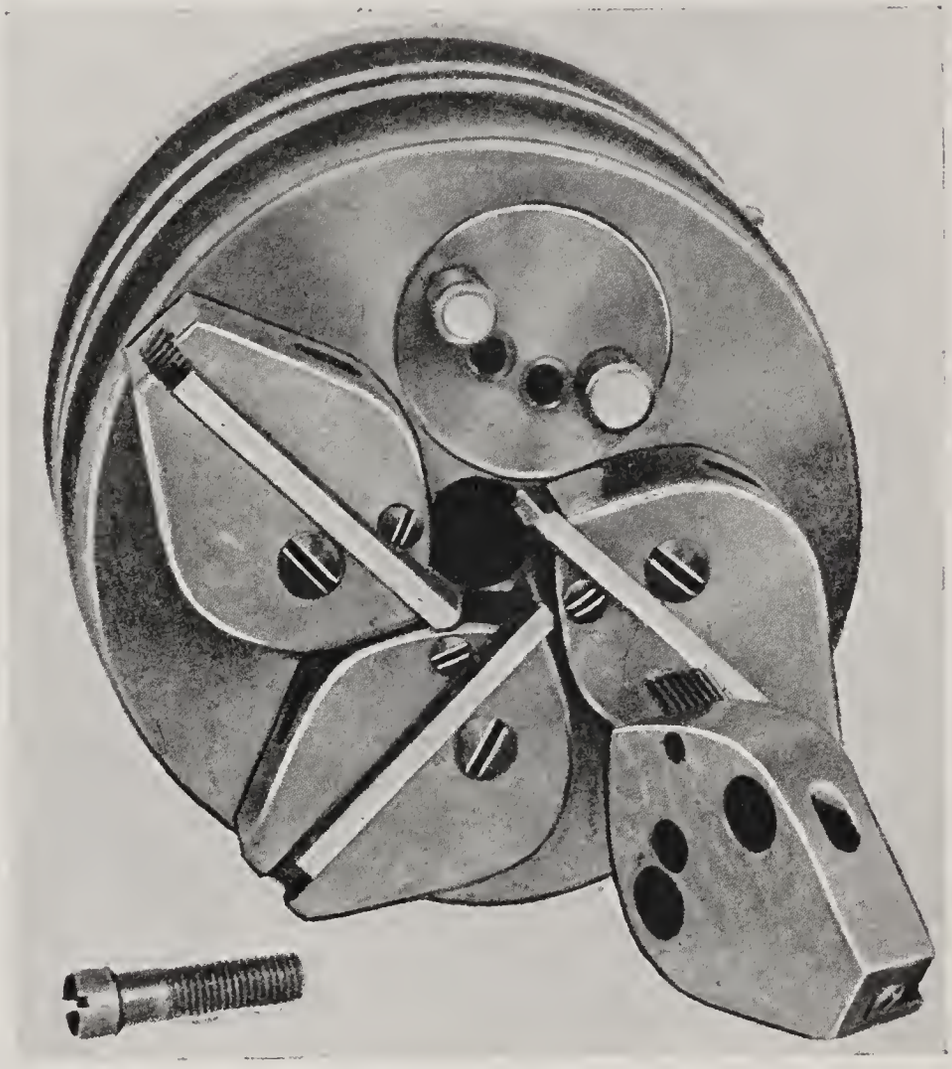

FIG. 128.

PATENT BOLT CUTTER.

The Landis Machine Co., Waynesboro', Pa.

This is a question which can only be settled by experience.

The blocks which hold the dies oscillate on spindles for opening and closing the cutting edges, and the spindles in turn are operated by the usual clutch ring with automatic release.

154. The Driving Mechanism.

The nature and arrangement of the driving mechanism naturally depends upon the size of the work to be done. Practically all machines, however, are geared, the spindle which carries the die head having a gear at the rear end, as in Fig. 129, engaging with a pinion on the cone pulley shaft.

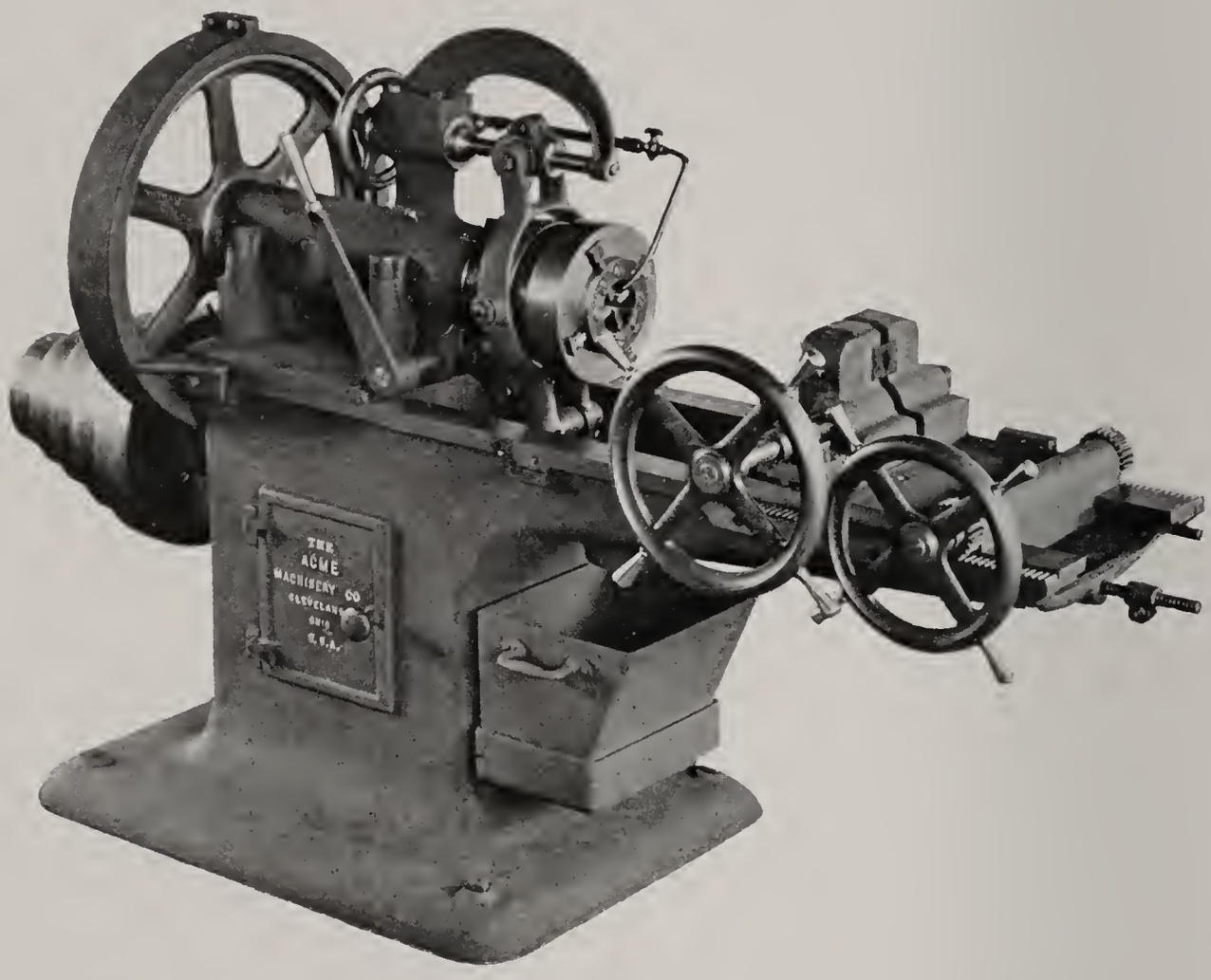

FIG. 129.

2-INCH SINGLE BOLT CUTTER.

The Acme Machinery Co., Cleveland, Ohio.

This arrangement assures a long and rigid bearing for the spindle, and removes the belt from danger of being spattered with oil. Four changes of speed is the usual number.

Fig. 130 represents a pipe-cutting machine, where the speed changes are effected by gearing.

As in this machine the work revolves instead of the dies, the spindle carries a gripping chuck at the front and a centring chuck at the rear end.

The belt runs always on one pulley and never needs to be handled, the six speeds of the spindle being obtained by manipulating the levers in front of the headstock. The spindle is driven by a large gear on the front chuck.

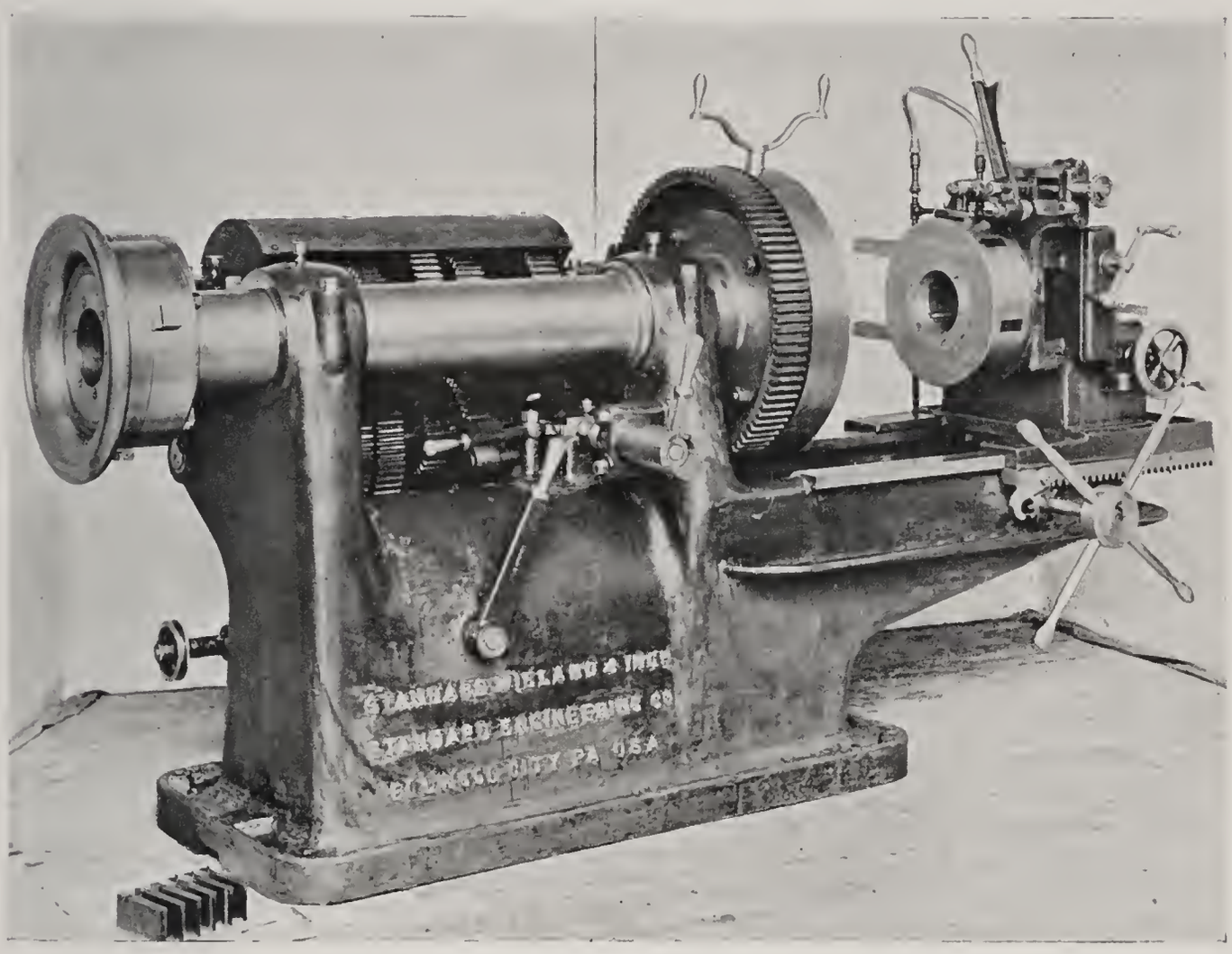

Fig. 130.

4-INCH PIPE THREADING AND CUTTING MACHINE.

The Standard Engineering Co., Ellwood City, Pa.

Small Machines are usually so arranged that they can be driven either by power or by hand.

Machines similar to that shown in Fig. 129 are sometimes made with two or three heads on one frame.

155. Carriage and Feed Mechanism.

The carriage of a bolt cutter usually consists of a simple vice, manipulated by screw and pilot wheel, for gripping the work.

The vice is attached to a plain slide operated by a rack

and pinion. These features are shown in Fig. 129. In the pipe-cutting machine (Fig. 130) the die head is carried in a somewhat similar manner upon a sliding carriage, and also has a transverse adjustment. Behind the die head is a tool post carrying a cutting-off tool. When this is in use, or when work is to be removed, the dies can be slid aside out of the way.

In ordinary bolt cutting the thread of the bolt itself may be depended upon to move the carriage during the operation of cutting.

When the thread has been cut to a sufficient distance the carriage automatically opens the dies and then closes and locks them again after the reverse.

When coarse threads are to be cut, or when special accuracy is desired, a lead screw attachment can be had with such machines as that shown in Fig. 129. It is of course necessary to provide a separate lead screw and nut for each pitch, but they are so constructed as to be readily changed. When a machine is confined to one class of work few changes would be necessary.

Screws can be cut in this way which are nearly as accurate as those made in an engine lathe, while the time of cutting will be about one-tenth as long.

156. General Design.

The single cabinet with overhanging frame is the most common type, as may be seen by reference to Figs. 129 and 130. The cabinet is provided with a broad base, and is usually one casting with the bed or ways.

The headstock may be bolted on, as shown in Fig. 129, or the whole frame of the machine may be one massive casting, as in Fig. 130. The overhang of the slides is balanced by a corresponding overhang of the headstock, or by the driving pulley and gears, as in Fig. 129. Special attention is given to this type of frame because the author

regards it as a particularly good design for machines having short beds. The conventional or lathe type of frame is sometimes used.

157. Feeds and Speeds.

The following table is published by the Acme Machinery Company of Cleveland, Ohio, and represents American practice in the matter of speeds, corresponding to a surface or linear speed of from 10 to 20 feet per minute. The same table can be applied to nut tapping.

TABLE OF SPEEDS FOR CUTTING BOLTS AND TAPPING NUTS.

Diameter.	10 Lineal Feet per Minute. Revolutions.	15 Lineal Feet per Minute. Revolutions.	20 Lineal Feet per Minute. Revolutions.
$\frac{1}{8}$	...	460	612
$\frac{1}{4}$	...	230	306
$\frac{5}{16}$	...	188	244
$\frac{3}{8}$	...	153	204
$\frac{7}{16}$	...	131	176
$\frac{1}{2}$	...	115	153
$\frac{9}{16}$	...	102	136
$\frac{5}{8}$	...	93	122
$\frac{3}{4}$	...	75	102
$\frac{7}{8}$	...	65	88
1	38	55	76
$1\frac{1}{8}$	34	50	...
$1\frac{1}{4}$	30	45	...
$1\frac{3}{8}$	28	40	...
$1\frac{1}{2}$	25	38	...
$1\frac{5}{8}$	23	35	...
$1\frac{3}{4}$	22	32	...
$1\frac{7}{8}$	20	30	...
2	19	28	...
$2\frac{1}{4}$	17	25	...
$2\frac{1}{2}$	15	22	...
$2\frac{3}{4}$	14	20	...
3	12	18	...
$3\frac{1}{4}$	11	...	...
$3\frac{1}{2}$	10	...	...
$3\frac{3}{4}$	9	...	...
4	8	...	...

158. Nut-Tapping Machinery.

As has been already noticed, most boring and drilling machines can be easily adapted for tapping by using proper chucks for the taps. This type of machine is, however, better adapted for tapping holes in castings or forgings which have been drilled in the same machine. For the simpler operation of nut tapping a multiple spindle machine somewhat similar to the multiple drill is efficient and economical. Such a machine is made by the Acme Company.

The spindles can be run at the same or different speeds, and are so driven by clutches that any one spindle may be stopped when necessary.

The spindles are counterbalanced and have spring sockets, so that the taps may be removed and replaced when the machine is running.

Four speeds are provided, and the machine is adapted to nuts from $\frac{1}{2}$-inch to $1\frac{1}{2}$ inches.

All bolt-cutting and nut-tapping machines should be provided with oil pumps, and for this class of work only pure lard oil or a mixture of lard oil and soda water is suitable.

159. Thread-Rolling Machines.

For producing screw threads on rough wire or forged blanks the rolling process has been used with success. The blank is rolled between two dies having grooves of the right pitch and inclination, and the thread is raised by displacement of the metal, so that the finished screw is larger in diameter than the blank. One die is usually stationary, and the other is reciprocated by a crank and pitman.

An automatic feed is attached when large quantities of screws of the same size are to be threaded. Machines are made of various sizes for threading wire from $\frac{1}{8}$-inch up to 1 inch in diameter.

Cold rolling a thread in this way on soft steel would tend to raise the elastic limit and the ultimate tensile strength of the metal.

CHAPTER XII

TENDENCIES IN MODERN MACHINE DESIGN

160. General Remarks.

A STUDY of the machine tools which have been put upon the market in this country during the past year or two will reveal some marked characteristics which may perhaps show something of the immediate future of machine design. The most of these have been noticed in previous chapters, as evidenced in particular classes of machines, in lathes or planers or milling machines.

A somewhat broader view of the machinery field will show that these characteristics are more or less common to all classes of machine tools, and that they point to certain definite tendencies in design which must be understood if the future is to be read aright.

The most noticeable tendency is unquestionably that towards the more general use of the electric motor, either directly or indirectly.

The majority of the larger machines illustrated in this book are adapted for electric transmission, and some are especially designed for connection with motors. The use of variable or constant speed motors, of countershafts or direct drives, will be discussed later. It is enough now to notice that electric driving is an established fact, and that machines in future must be so designed as to accommodate the motor and the controllers.

Another noticeable tendency, and one which is more or

less a corollary to the one just mentioned, points to the gradual abandonment of belts on machine tools and the substitution of gears and silent chains. Compactness and unity of design call for a motor bolted to the frame of the machine, a location which usually makes the line of centres too short for the successful application of belts.

The evil of the short belt and the inconvenience of the speed cone have led to the substitution of gear boxes in feed mechanism on all classes of machines. There seems to be no good reason why a similar change may not benefit the driving mechanism. The amount of gearing necessary for speed changes is again dependent on the type of motor used, and this subject is reserved for later discussion.

The great increase in power and capacity for work which is so marked a characteristic of modern machinery is more or less involved with the tendencies already noticed. As a result of keen competition among those who use such machinery there is a continual striving for increase of output. Every additional piece that a given machine will finish in a given time, represents not only a saving of interest on its cost but a saving in labour and in every item of shop expense.

The use of wider and faster belts, of heavier gears and spindles, and of more massive frames, means more power and more work per machine. Reference is not here made to the increase in size of machines which is also noticeable, but rather to the concentration of metal and of power in medium-sized machines.

The 16-inch lathe of ten years ago consumed but one horse-power, and that only when crowded to the capacity of its narrow, sluggish belt. The modern lathe of the same swing will consume double the amount of power, and, if specially fitted for the use of high-speed steels, may use 10 or 12 horse-power.

The increasing use of high-speed steels is another factor which must be reckoned with by designers of machinery in

the future. Its use is not confined to lathes and planer tools, but is extending to twist drills and milling cutters.

Finally, machine tools are being made more automatic in character, and both the number of cutting tools and the number of simultaneous or consecutive operations are being largely increased. The various developments just mentioned will be considered somewhat in detail in this chapter, and some further data and illustrations given.

161. Electric Driving.

It is not necessary at the present time to argue in favour of electric transmission. The superior economy of this kind of driving, the clear head room afforded for crane service, the greater cleanliness and light due to the absence of overhead belting and shafting, and the flexibility as regards changes and extensions, are all familiar reasons for its general adoption.

The recent improvements in speed control furnish another potent argument for the use of the new motive power. The question to-day is not so much whether to use electricity, but how to use it to the best advantage. The manufacturer must first decide whether he will use individual motors on each machine, or whether it will pay better to group his machinery and use short line shafts driven by motors. In general it may be said that large machines, consuming more than one or two horse-power and run at widely varying speeds and loads, should be equipped with independent motors.

Smaller machines which are more or less alike, and which are run continuously on uniform work, can be economically grouped together in bunches of from six to ten and driven by a shaft either overhead or underneath, the shaft being connected to the motor by belt, chain, or gears. If the shaft runs at a moderate speed, the connection with the motor may be such as to permit of the use of a relatively small high-

speed motor, at a considerable saving in first cost. If the machines have an intermittent, jerky motion, like planers, shapers, or presses, the shaft had better run at a comparatively high speed and be equipped with one or more flywheels to equalise the load on the motor and permit of the use of a smaller unit.

The next important question to be decided is that of the type of motor to be selected, whether direct or alternating current, constant or variable speed, and if variable speed, how the motors are to be regulated.

If the group system of transmission is to be employed, the alternating current with induction motors offers the best solution on account of the simplicity and durability of this type of motor. It has no rubbing contacts, and requires no more care than an ordinary countershaft.

In such case, all speed changes and all stopping and starting must be effected mechanically between the line shaft and the machine, or in the latter, since the induction motor must at all times run in phase with its generator. The motors can be stopped or started from the engine-room the same as shafting, and of course any motor can be disconnected by means of a switch. The direct-current exciter can be made large enough to supply current for power if desired.

If variable-speed motors are to be used, either wholly or in part, the direct current will usually be the more economical and convenient, since it can be used equally well for constant or variable speed machines. A direct current may be obtained from the alternating system by a motor generator, but this is a rather expensive method.

On large machines with individual motors it is well to have electric speed control, and this may be effected in several ways.

1. By introducing resistance into the armature circuit.
2. By introducing resistance into the shunt field circuit.
3. By a multiple voltage system of wiring.
4. By a combination of two of the above.

The objection to No. 1 is the waste of energy in the rheostat, and the variations of speed with change of load.

No. 2 can only be used for increasing the speed above the normal, and that only to about 30 per cent. on account of sparking at the commutator.

No. 3 is the method which is received with most favour at present, either alone or in combination as in No. 4.

The three-wire system with two voltages, as introduced by the Westinghouse Company, is probably the best known of the multiple voltage arrangements. By means of a specially constructed generator a difference of potential of, we will say, 250 volts is maintained between the two outside wires, while the middle wire differs from either of the others by 125 volts.

A 250-volt shunt motor being connected to the outside wires, runs at normal speed, but when connected to one of the 125-volt circuits, runs at half speed. Speeds intermediate between half speed and the normal, or speeds above the normal, can be obtained by method 2.

The four-wire system as installed by the Allis-Chalmers-Bullock Company, furnishes six independent voltages of 60, 80, 100, 140, 190, and 250 volts, by the various combinations possible, and thus gives a much greater range of speeds than the three-wire, and with finer gradations. It is entirely possible to obtain the intermediate speeds with shunt field resistance, since the intervals correspond to about 30 or 35 per cent.

In order to obtain these different voltages it is necessary to use, in addition to a 110-volt generator, a motor generator of special design, and this in addition to the cost of wiring makes the system rather too expensive for ordinary shops. A three-wire system similar to the above differs from the Westinghouse, inasmuch as it has three voltages instead of two.

Summing up the various systems outlined, it may be said that it is possible with some loss of efficiency to obtain a

speed variation of 2 to 1 or 100 per cent. by a two-wire system using methods 1 and 2. That with a three-wire system a speed variation of 2 to 1 can be secured economically, and 3 or 4 to 1 by the use of shunt resistance. That the four-wire system gives a range of 4 to 1 directly, and by the introduction of resistance a possible variation of 7 or 8 to 1.

In any of these systems the motor will need to be larger than if working always at the maximum speed. With the rheostat control this increase will be as the square of the speed variation, while with the multiple voltage the size will increase in the same ratio as the speed variation. This is a strong argument in favour of the latter method of regulation.

The next problem that confronts the owner of machine tools is that of mechanical *versus* electrical speed control. To a certain extent this is dependent on the electric system used. If constant-speed motors and the group system are selected, it naturally follows that the speed must be regulated entirely by mechanical means.

When independent motors are used on each machine, electric speed control may be adopted to whatever extent seems desirable. Most of the electrically driven machines which have been illustrated in previous chapters are equipped with constant-speed motors and change gears. This method permits of the use of relatively small high-speed motors, but does away with the advantages secured by electric control. The objection to step cones is the coarse scale of speed gradations and the time consumed in shifting the belt. Nests of gears are more convenient and will be more used, but even these do not afford the fine gradations which can be obtained by the use of the electric controller.

For machines of small or medium size the combination of the constant-speed motor and the change gears is satisfactory, but larger and more expensive machines should have a more complete scale of speeds, and the speed control should be so convenient that it may be used at all times and the machine

always run at the exact speed which will give the maximum output.

These results are best attained by the combination of a variable-speed motor with mechanical devices, in such a way that the coarser gradations are obtained by the gearing, and the intermediate shading is done with the controller. For large machines a three-wire system, combined with rheostat control and giving a total speed variation of 4 to 1, will usually answer all requirements. At the beginning of any particular operation the mechanical control can be adjusted so that the normal speed of the motor will give the average speed desired.

If the electric controller is properly located for the convenience of the operator, he may then, without leaving the work, shade the speed up or down as the character of the operation may require. Planing, shaping, and slotting machines will need only the electric control, as this will give the necessary range of speeds. Variable-speed countershafts have been used to some extent in place of the electric controller, but it is safe to say that, up to the date of this writing, no entirely satisfactory device of this character has been put upon the market.

With tools of medium size, a 2 to 1 electric variation, combined with change gears, gives a satisfactory solution. The best means of connection between motor and machine is still an unsettled problem.

The various methods still employed have already been illustrated in former chapters—belting, gearing, and chain drives. It is probable that the use of the belt on machine tools will be very limited in the future.

To furnish the power necessary to drive the modern machine a belt needs to have either excessive width or excessive speed, and is certain to be displaced ultimately by the silent chain, as the latter is stronger, more compact, and more positive in its action.

Under some circumstances steel and raw-hide gearing is

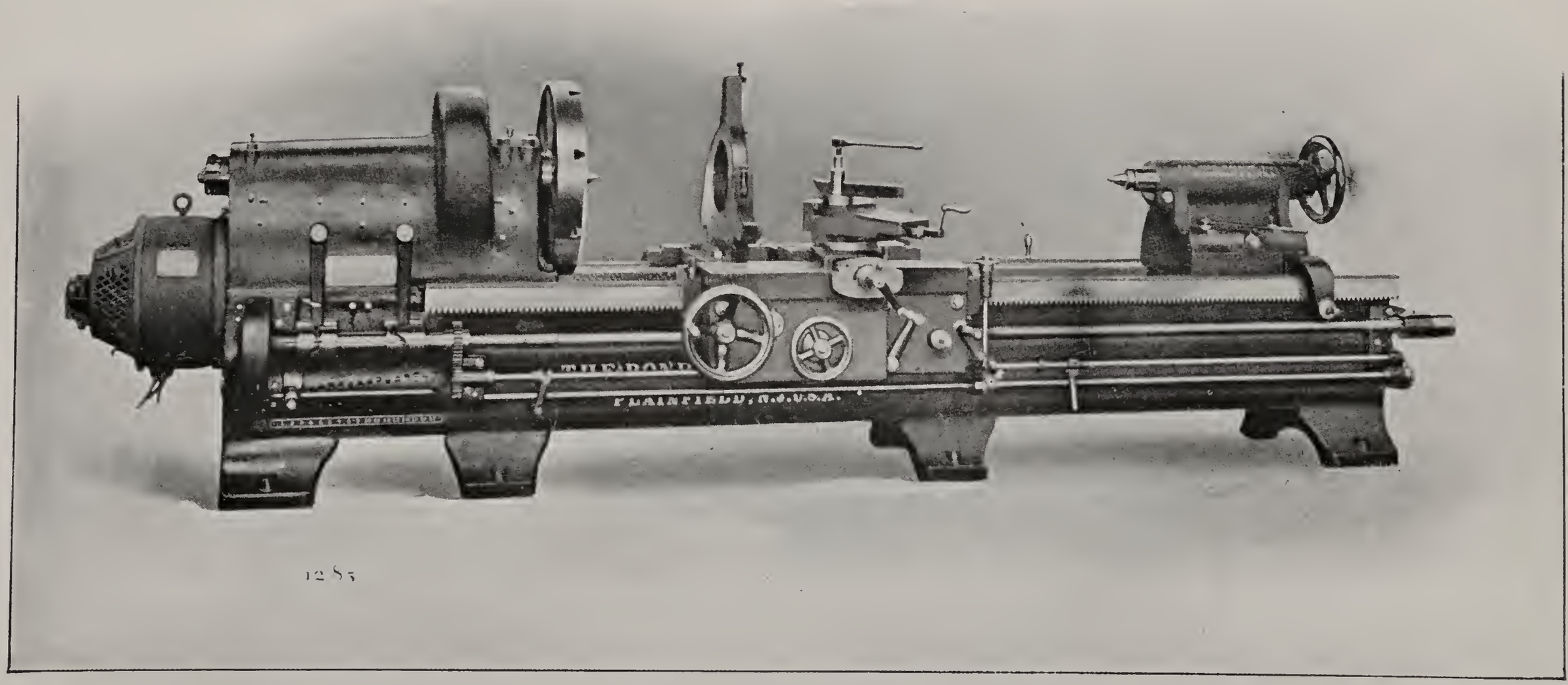

FIG. 131.

28-INCH POND NEW MODEL ENGINE LATHE.

The Niles-Bement-Pond Co., New York.

preferable to either of the above, making possible a more compact and self-contained machine.

One feature of electrical control that deserves special notice is the possibility of locating the controller near the hand of the operator, so that, without moving from his position or taking his eyes from the work, he may instantly change to the desired speed.

This means that he will be much more apt to use the best speed than if he has to travel the length or the width of a big machine and shift a belt or change a gear.

One thing more needs to be done, and that is to build machine tools with special reference to the electric drive.

Too many of the modern machines show by their appearance a clumsy adaptation to electric motive power, rather than a convenient and harmonious design.

This is due to the fact that it has heretofore been necessary to consider both mechanical and electrical means of driving in the same machine at some sacrifice for either.

Electrical transmission has now reached a point in its development where it justifies the building of machines intended for electric driving exclusively. Some of our machine tool manufacturers recognise this, and are now advertising such machines.

The new model 28-inch lathe shown in Fig. 131 is a good example of a machine built for the motor and a motor built for the machine. A variable-speed motor is used having a range of 2 to 1. The controller is at the right of the carriage, and by its means fifteen speeds can be secured. By means of another crank on the apron four changes of gearing are made possible, making in all sixty different speeds which can be controlled by the operator without leaving the work.

Another tendency, already hinted at in what precedes, is evinced by the increasing demand for stronger and heavier machines.

The 18-inch lathe of a decade ago weighed perhaps

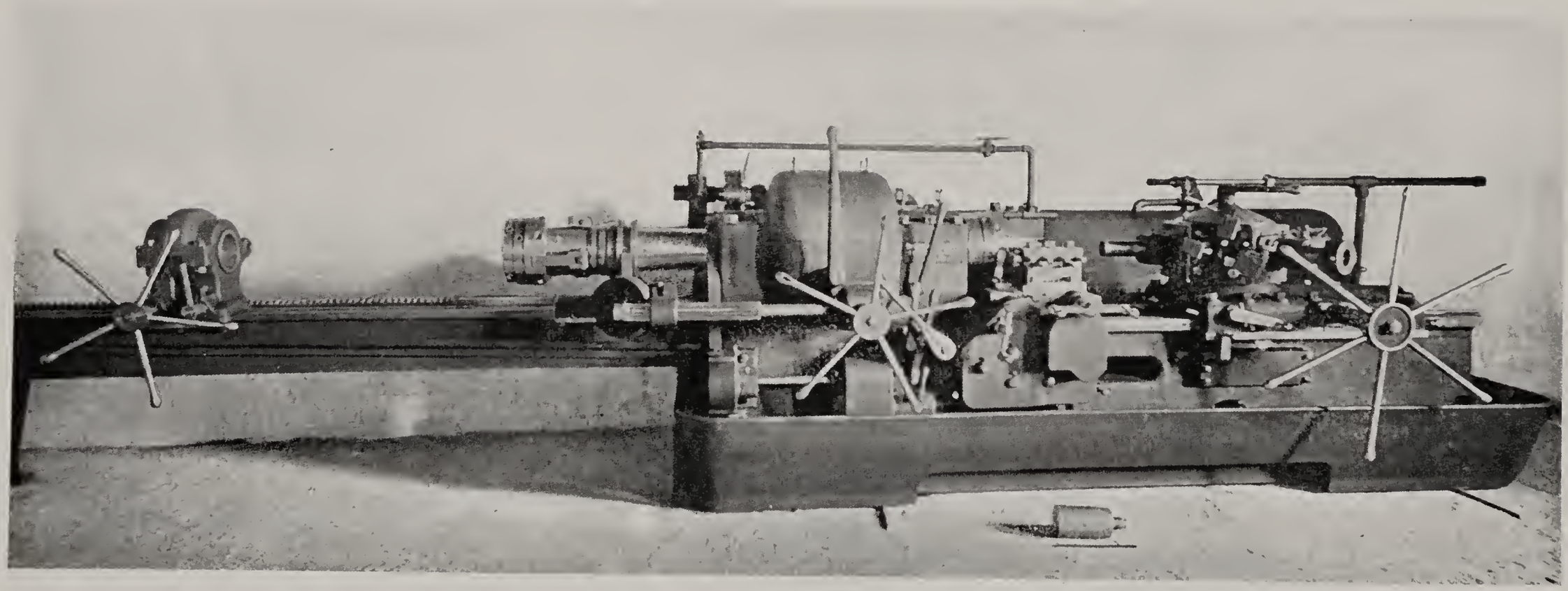

FIG. 132.

6-INCH FORMING LATHE.

Bardons and Oliver, Cleveland, Ohio.

2000 lbs., was capable of taking only a light chip at the full swing, and consumed a maximum of perhaps 2 horse-power under the most favourable conditions. A modern lathe of the same nominal capacity weighs, we will say, 3000 lbs., and if designed for use with high-speed steels, will consume from 5 to 15 horse-power. So many examples have been given in previous chapters that it is not necessary to do more than allude to this development here.

The remarkable growth in the use of turret lathes and forming machines for reducing metal is but another step in the same direction. Some of the records made by machines of this class in removing large quantities of metal and in finishing large numbers of parts in a limited time have already been noticed in Chapter IV.

One of the largest turret lathes yet made is illustrated in Fig. 132.

This machine is adapted to the use of high-speed steel tools, and is capable of handling bar stock 6 inches in diameter.

The spindle is driven by a 7-inch belt, and twelve speeds can be obtained without stopping the machine. As an example of the capacity of this lathe, it may be said that a locomotive wrist pin $4\frac{1}{2}$ inches in diameter and $10\frac{1}{2}$ inches long over all has been finished from $4\frac{7}{8}$-inch steel bar stock in eighteen minutes.

Fig. 133 illustrates the latest development of the 'flat turret' lathe electrically driven (see Fig. 49).

The use of the high-speed or air-hardening steel is naturally one of the principal factors in the increase of output. Although this class of steel was first invented and applied by Americans, it must be admitted that up to the present time our British cousins have made more use of the invention than we have ourselves, and they know more of its possibilities.

American manufacturers are now waking up to the importance of the new discovery, and machines are on the market which are specially adapted for its use.

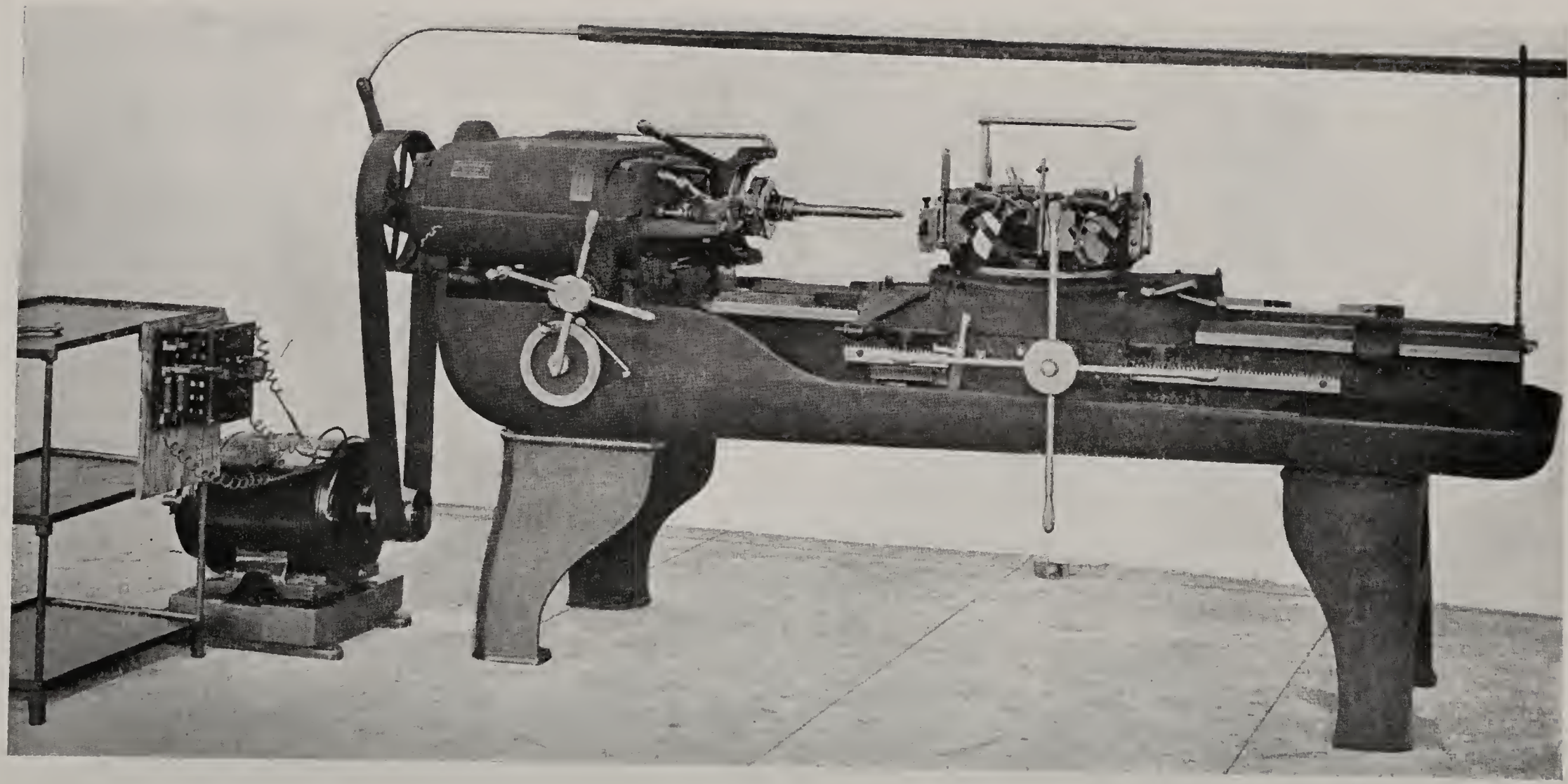

FIG. 133.

NEW FLAT TURRET LATHE.

Messrs. Jones and Lamson Co., Springfield, Vermont.

One of these has already been illustrated as in Fig. 37, and another is shown in Fig. 134.

A 30-inch rapid-reduction lathe exhibited at the St. Louis Exposition was equipped with a 25-horse-power motor, a fact which speaks plainly as to what is expected in the way of removing metal.

Mention has been made in Chapter VII. of the results obtained in high-speed milling.

Experiments recently made by the Cincinnati Milling Machine Company, and reported in the *American Machinist*, throw some light on the endurance of high-speed steel when used in milling cutters.

An ordinary spiral mill of Novo steel, running at a surface speed of 82 feet per minute and with a feed of 27 inches per minute, has cut 6800 inches of grey cast iron without sharpening, or more than five times what an ordinary carbon steel cutter could do at about half the feed.

Other tests with cutters of various shapes gave similar results.

There is no doubt as to the fact that machine tools are becoming more elaborate and complicated.

While this in itself is a disadvantage, it may be justified by a greater capacity and a larger output. Every machine must be judged by the ratio of earning power to interest on the investment, and if a certain tool costs more than its neighbour, it must do better work or more work to pay for the difference.

It is but fair to the new tools to say that the added complication has come about from the attempt to solve the problem of speed and feed control satisfactorily. It is not enough to provide the proper gearing for speed and feed changes, but it must be so arranged that the changes can be made by the operator without too much trouble.

The endeavour to bring the reversing gear and the driving speed control to the apron of the engine lathe has been responsible for much of the increased mechanism which is so

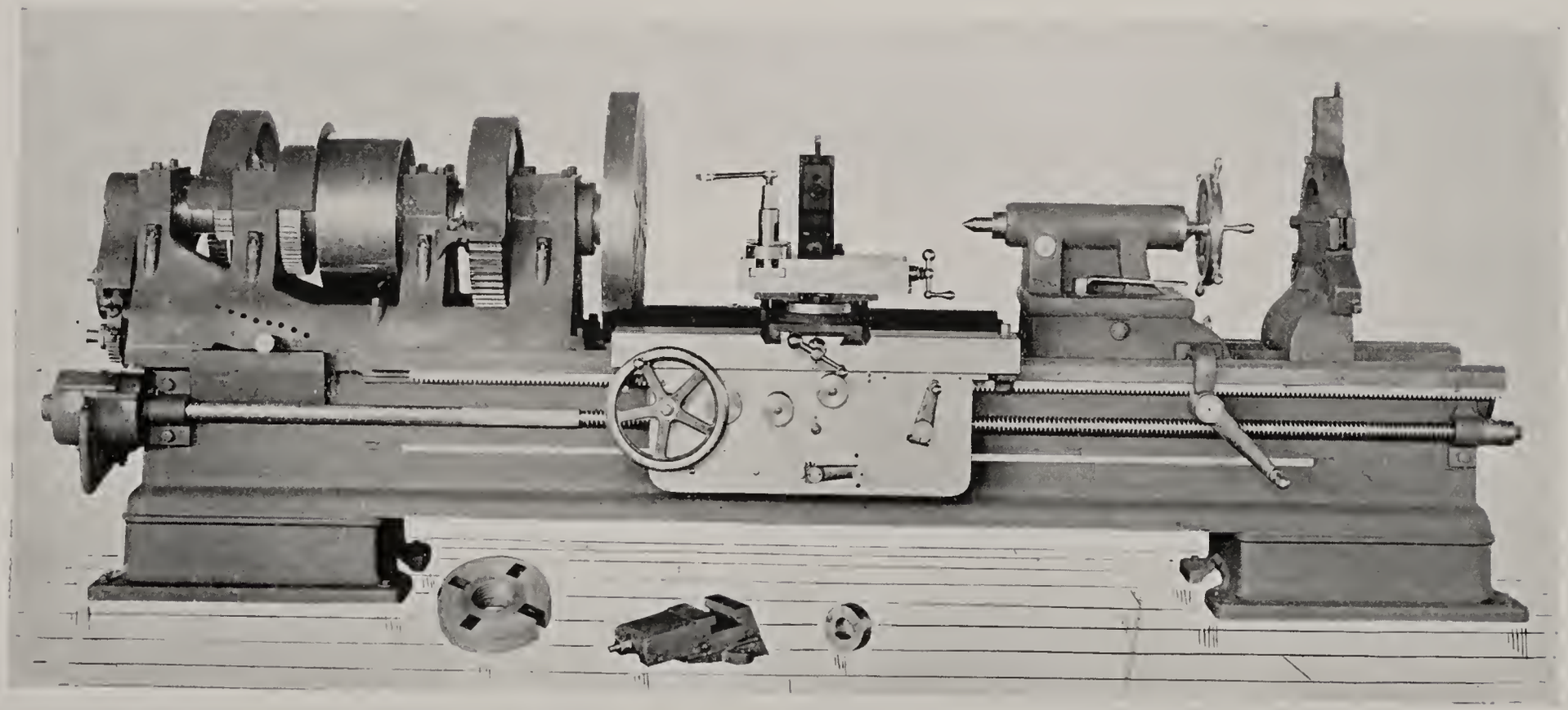

FIG. 134.

30-INCH PATENT HEAD LATHE.

The Lodge and Shipley Machine Tool Co., Cincinnati, Ohio.

evident, and similar statements may be made in regard to other machines.

Specialisation is the order of the day, and to a certain extent the turret lathe and the milling machine are bound to displace the engine lathe and planing machine. As has been already noticed in other chapters, a multiplicity of tools and of cutting edges, which enables a machine to perform a number of operations simultaneously or consecutively, is the characteristic of special machines. The remarkable records of work done by such machines are due to this characteristic, and are only made possible when large numbers of similar pieces are to be finished.

For the ordinary work of the machine shop and for operations on single pieces our old friends the engine lathe, the planer, the drill press, and the boring mill will always be needed. They will be more powerful, more convenient, and more automatic in action, but they will continue to be the mainstays of every shop doing miscellaneous work. In all metal-cutting machinery, the general tendency is and will be to increase the amount of work done by the machine and to reduce to its lowest terms the human labour required.

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